Networks used for interpretation of speech-in-noise in children with unilateral sensorineural hearing loss

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Introduction

Standard audiometric tests, such as Otoacoustic Emission (OAE) and Auditory Brainstem Response (ABR), are able to detect cochlear and retrocochlear hearing deficits, respectively, where the source of the deficit is either from injury to the hair cells in the cochlea or the auditory pathway from the cochlea, through the olivary complex, lateral lemniscus, inferior colliculus, thalamus (medial geniculate body), and finally into Heschl's gyrus. However, some auditory pathologies, termed central auditory processing disorders, are cortical in etiology. Clinical audiological testing procedures, such as time-compressed sentences, or speech-in-noise, may be useful for diagnostic purposes but cannot give information on the underlying neuroanatomical basis of the deficit. Here we use functional MRI (fMRI) in conjunction with an audiological test performed in-scanner to investigate the source of auditory processing deficits in children with unilateral sensorineural hearing loss (USNHL). Children with USNHL have shown deficits in central auditory processing tasks such as speech-in-noise [1], and these deficits may also be associated with side of hearing loss [2]. We use group Independent Component Analysis (ICA) in order to identify networks associated with interpretation of speech-in-noise.

Materials and Methods

fMRI data was acquired from nine children (mean age = 9.1 ± 1.7 yrs) on a Siemens 3T Trio system. Scan parameters were: TR/TE = 2000/38 ms, SENSE factor = 2, matrix = 64 X 64, FOV = 22 X 22 cm, slice thickness = 5 mm. Severe-to-profound USNHL with normal hearing in the other ear was confirmed via standard audiometry. Five of the children have left USNHL and four have right USNHL. IRB approval and informed consent was obtained from each subject's parent or guardian (assent was obtained from children 8 years and older).

The Speech-In-Noise (SIN) test was modified for use in children from a previously developed SIN test [3] and utilizes the Bamford-Kowal-Bench (BKB) sentences [4]. The sentences are spoken by a male speaker and presented over four-talker babble at varying SNR. For the fMRI experiment, SNRs of 21dB, 12dB, 6dB, and 0dB were used. A specially-designed MR-compatible audio system was used for the task, including ER-30 insert headphones with very low ambient noise of < 10 dB SPL. All stimuli were calibrated using a B & K audiometer to 80-85 dB SPL. The HUSH scan sequence [5] was used, enabling the presentation of stimuli during completely silent gradient intervals.

Data was processed via in-house software written in IDL (Research Systems Inc., Boulder, CO). Group ICA [6] was used for data analysis. Associated time courses from each subject were used to determine task relevance, regressing with task difficulty as the parameter of interest. Frames were discarded if 1) there was excessive motion, judged using a cost function and a threshold obtained from visual analysis; or 2) the subject did not respond, indicating failure to understand the speech over the babble. Since this resulted in unequal numbers of frames from each subject, an expectation-maximization restricted maximum-likelihood (EM-ReML) [7] algorithm was used for detection of significance. Significance was tested for overall differential group activation, as well as significant differences between children with left and right USNHL.

Results

Two components related to attention were found (Figure 1, top) with activation in the superior and middle frontal gyri (BA 10/46). Two components related to auditory processing were also found (Figure 1, bottom). One of the components displayed activation in the superior and middle temporal gyrus (BA 21/22; Figure 1, bottom left) while another displayed activation in the left inferior frontal gyrus (BA 45/47; Figure 1, bottom right).

Components were also found with differences between children with right and left USNHL. Children with left USNHL showed greater activation (Figure 2, left) in the middle occipital gyrus (BA 18/19) while children with right USNHL showed greater activation (Figure 2, right) in the right superior temporal pole (BA 38/22) and in right medial temporal lobe areas (hippocampus/hippocampal gyrus).

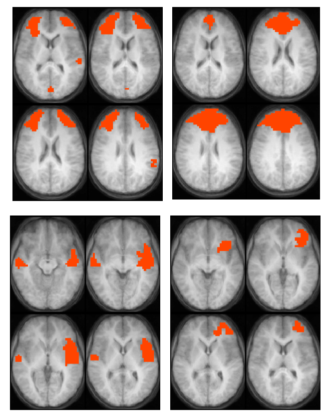

Figure 1. Group IC maps significant for interpretation of speech-in-noise in a population of children with left and right USNHL. Maps have T > 3 and cluster size of 12. Time courses significant for differential activation with task difficulty at nominal p < 0.02.

Discussion

Greater understanding of the neuroanatomical basis for interpretation of speech-in-noise, and deficits in speech-in-noise and other central auditory processing tasks, is critical for the designing of improved management strategies for children with USNHL and other populations which show central auditory processing deficits. Our specialized procedures, including a specially-constructed MR-compatible audio system and silent-gradient scan sequence, now make possible in-scanner performance of auditory processing tests and thus elucidation of the specific cortical networks involved.

As expected, increasing task difficulty recruited frontal attentional networks (Figure 1, top). Classical Wernicke's area was also recruited (Figure 1, bottom left), as well as the left inferior frontal lobe (Figure 1, bottom right). Wernicke's area has been hypothesized to be involved more with spectral/temporal processing of sound rather than word recognition [8], and our results support this interpretation. The area of the inferior frontal lobe (BA 45/47) has been shown [9] to be recruited for semantic processing, as opposed to syntactic processing, which recruits a more superior area of the left IFG (BA 44/9). Thus, this area may be recruited for using semantic clues to interpret a word in a noisy environment.

Differences in cortical activation were also seen dependent on the side of hearing loss. Children with left USNHL preferentially recruit the occipital lobe (Figure 2, left) while children with right USNHL preferentially recruit right superior and medial temporal regions (Figure 2, right). These results may indicate differing cortical reorganization and compensation strategies between children with right and left USNHL.

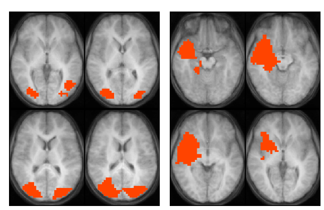

Figure 2. Group IC maps significant for interpretation of speech-in-noise in children with left and right USNHL. Maps have T > 3 and cluster size of 12. Time courses significant for: children with left USNHL > children with right USNHL (left); right USNHL > left USNHL (right) at nominal p < 0.02.

Conclusion

A central auditory processing task, interpretation of speech-in-noise, was performed in-scanner by a cohort of children with left or right USNHL undergoing fMRI. Using group ICA, increasing task difficulty (decreased SNR of the speech) recruited frontal attentional networks, Wernicke's area and its RH homolog, and the left inferior frontal gyrus (BA 45/47). Differences related to side of hearing loss were also found in the occipital lobes and in the right temporal pole and medial temporal areas. Results show the potential usefulness of fMRI for greater understanding of the neurophysiological bases underlying central auditory processing and central auditory processing deficits.

References

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