The Neural Correlates of Interpreting Speech-In-Noise in Children with Unilateral Sensorineural Hearing Loss Investigated using a Functional MRI Paradigm with Silent Gradient Intervals

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Introduction

Children with unilateral sensorineural hearing loss (USNHL) have shown deficits in central auditory processing tasks such as speech-in-noise [1] and sound localization [2]. A previous functional MRI (fMRI) study has shown evidence for cortical reorganization in children with USNHL for base-level auditory processing [3], as well as differences between children with left and right USNHL. The use of specialized pulse sequences involving silent gradient scanner intervals [4-5], enables the translation of audiological testing procedures, such as speech-in-noise (SIN), from the audiology booth to the fMRI scanner, and the investigation of the neural correlates of central auditory processing deficits such as those suffered by children with USNHL. Here fMRI data is presented from two children with USNHL performing the Bamford-Kowal-Bench (BKB)-SIN test (Etymotic Research, Inc.; Elk Grove Village, IL).

Materials and Methods

Data was acquired on a Siemens 3T Trio system. EPI-fMRI scan parameters were: TR/TE = 2000/38 ms, BW = 76.8 kHz, SENSE factor = 2, FOV = 22 X 22 cm, matrix = 64 X 64, slice thickness = 5 mm. The modified Hemodynamics Unrelated to Sounds from Hardware (HUSH) pulse sequence [6] was used, consisting of a 5-second period with completely silent scanner noise for auditory presentation followed by a 6-second data acquisition block. Auditory stimuli were presented using Presentation software (Neurobehavioral Systems, Inc.; Albany, CA). The stimuli consisted of the Bamford-Kowal-Bench (BKB) sentences [7] spoken by a male speaker over four-talker babble. The sentences were presented at 21 dB, 12 dB, 6 dB, and 0 dB SNR. In addition there was a control stimulus consisting of narrow-band noise with center frequencies of 500 Hz and 1 kHz. Each stimulus type (BKB-SIN at the various SNR levels and control) was presented 8 times, for a total number of 40 stimuli and a total scan time of 7:20. Stimuli were presented using a specially constructed MR-compatible audio system with low (≤ 10 dB SPL) ambient noise [8] using ER-30 insert earphones (Etymotic Research, Inc.; Elk Grove Village, IL). Using a B & K calibrated sound meter, the volume levels of the sentences were adjusted such that they were presented between 80-85 dB SPL.

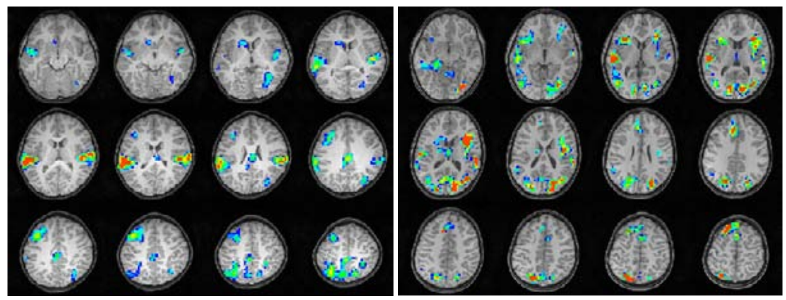

Figure 1. Functional activation from two subjects performing the Bamford-Kowal-Bench Speech-In-Noise (BKB-SIN) task of listening to sentences spoken by a male speaker over four-talker babble at varying levels of SNR. The left activation map is from a 7-year-old girl with severe sensorineural hearing loss in the right ear; the right map is from a 7-year-old boy with severe sensorineural hearing loss in the left ear. Colored voxels have $p < 0.01$ ($T > 3.5$) for correlation of activation with task difficulty. Images in radiologic orientation.

The paradigm was performed by two subjects with severe unilateral sensorineural hearing loss (USNHL): a seven-year-old girl with hearing loss in her right ear, and a seven-year-old boy with hearing loss in his left ear. Both subjects had 80 dB hearing loss (HL) or greater in the deaf ear, as measured by pure-tone audiometry (PTA); and normal hearing (< 20 dB HL) in the other ear. In-scanner performance data was acquired via a squeeze ball connected to the parallel port of the PC running Presentation. The subject was instructed to respond if s/he was able to understand at least one word of the spoken sentence over the babble. Data was processed using in-house routines written in IDL (Research Systems Inc.; Boulder, CO). Due to the variation in MR signal baseline caused by the acquisition sequence, the data were grouped into the first, second, and third volumes acquired after the auditory stimulus presentation periods and processed separately. Only trials where the subject responded (indicating comprehension of the male talker over the babble) were included in the analysis (the control trials were not included in this analysis). The MR signal for each trial was correlated with the task difficulty (the dB SNR) using a non-parametric regression. The signed squares of the three Spearman's Rs were averaged and converted into a T-score. The T-score maps were filtered with a Gaussian filter of $\sigma = 4$ mm to increase the SNR. The T-score maps were then overlaid on the T1-weighted MP-RAGE whole-brain anatomical datasets.

Results and Discussion

The seven-year-old girl with severe hearing loss in her right ear responded to each of the stimuli, indicating she understood at least one word in all sentences heard. The seven-year-old boy with severe hearing loss in his left ear performed much worse; while he responded to each of the sentences presented at 21 dB and 12 dB SNR, he responded to only one of the sentences presented at 6 dB and none of the sentences presented at 0 dB SNR. For the girl with USNHL in the right ear (Figure 1, left), increasing the difficulty level of the paradigm resulted in the recruitment of the auditory cortex bilaterally, the right prefrontal cortex, the right inferior parietal lobule, the right caudate, the posterior cingulate, the left angular gyrus, the left precuneus, and the left lingual gyrus. For the boy with USNHL in the left ear (Figure 1, right), increasing the difficulty level of the paradigm resulted in the recruitment of different areas, including inferior, middle, and superior occipital areas bilaterally; the anterior insula bilaterally; the anterior cingulate; and the right inferior temporal gyrus. These results provide preliminary evidence of a right-lateralized network, including the prefrontal cortex and inferior parietal lobule, being recruited for the task of interpreting speech-in-noise, as seen in the girl with USNHL. For the poorer-performing boy with USNHL, the occipital cortex activation corroborates the previously hypothesized phenomenon of cross-modal plasticity (recruitment of visual areas for auditory processing) interfering with speech processing in hearing-impaired children [9].

Conclusion

The neural correlates of the central auditory processing task of interpreting speech-in-noise were investigated using an fMRI acquisition scheme incorporating silent scanner intervals in two children with USNHL. Preliminary results suggest this task recruits a right-hemisphere network incorporating the prefrontal cortex and inferior parietal lobule. Future results from the complete study (N = 40) of children with USNHL should further elucidate the neural circuitry supporting speech-in-noise, and possible influences of side of hearing loss and gender.

References

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