An fMRI study of the neural mechanisms of second and fourth tone recognition in deaf children

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Abstract. Tone is an important component of language and it plays a key role in language comprehension and communication. However, children with hearing loss face challenges in vocal tone recognition due to hearing impairment. In this study, five deaf children and two children with normal hearing were recruited to compare the differences in second and fourth tone recognition tasks between deaf and normal children. The results found that (1) some of the deaf children's brain regions for processing vocal tones did not work properly due to hearing loss; (2) deaf children may rely on different neural networks when processing vocal tone information. (3) Deaf children process vocal tone information with hemispheric characteristics.

Keywords: deaf children; Tone; fMRI; data analysis.

1. Introduction

Tone is an integral part of speech and plays an important role in the perception and comprehension of speech sounds[1] . However, for deaf children, they may differ from normal children in vocal tone recognition due to their inherent hearing deficits. Studying the neural mechanisms of vocal tone processing in deaf children helps us to better understand the process of language processing, and is especially important for the language development of deaf children.

Functional magnetic resonance imaging (fMRI) techniques have played an important role in revealing the neural mechanisms of brain processing.[2] . fMRI is a non-invasive neuroimaging technique that can measure changes in blood oxygen levels in the brain, thus reflecting the activity of various brain regions under different tasks. It provides a powerful tool to study the neural mechanisms of speech perception. By using computer technology to process and analyze fMRI data, it is possible to compare the activation areas and levels of activation in deaf and normal children during tone processing tasks, which in turn allows us to understand the specific neural mechanisms involved in language development in deaf children. fMRI technology provides a new perspective on the neural mechanisms of tone recognition in deaf children[3] .

The purpose of this study was to discuss the differences in brain activation areas between deaf and normal children in second and fourth tone recognition tasks. Computer-based analysis of fMRI imaging data from deaf and normal children reveals differences in vocal tone processing between deaf and normal children. Through this study, we hope to better understand how deaf children process vocal tone information and to provide them with better education and rehabilitation programs.

2. Materials and methods

2.1 Subjects

Native Mandarin-speaking children (N=7.00 male; right-handed; age=20.9±2.3 [mean±SD] years) were recruited from Tianjin to participate in this study. Five of them were deaf children (DC),and two were hearing children (HC). All participants underwent a physical examination prior to the start of the study to ensure that they were physically healthy and fit to participate in this experiment. Participants with HC reported no neurological or hearing-related impairment and had normal or corrected real vision.

2.2 Stimulation

The stimuli used for the experiments consisted of 96 pairs of vocal tones, each pair consisting of two tones at a frequency of 500 Hz and a duration of 100ms. The tones were generated using E-prime (Psychology Software Tools, Inc., version 2.0). The voice pairs consisted of four tones: "one", "two", "three" and "four", each with Each tone has four different combinations, and the tones are presented in a random order within two blocks.

2.3 Experimental steps

We performed functional magnetic resonance imaging (fMRI) while the participants performed a tone recognition task. First, four identical hanyu pinyin characters appeared on the screen simultaneously, each with the vocal tones of "一", "二", "三", and "四". Next, the participants were instructed to listen to the sounds and to place them according to the pitch pattern by pressing the "1", "2", "3", or "4" buttons to classify them into one of four categories based on pitch patterns.

2.4 fMRI data acquisition

All MRI data were acquired using a Siemens 3-Tesla PRISMA MRI system and a 32-channel head coil at the General Hospital of Tianjin Medical University. Resting-state fMRI images were acquired by gradient-echo (GRE) multiband multi-excitation echo-planar imaging (multiband-EPI) sequence: TR/TE=800/30ms, flip angle=56°, field of view (FOV)=104 * 104mm, layer thickness 1.5mm. Finally, T1-weighted high-resolution structural images were acquired using magnetization-prepared rapid gradient-echo (MP-RAGE) with the following parameters: 188slices, TR=2000ms, TE=2000ms, flip angle=8°.

2.5 fMRI data preprocessing

The fMRI data were preprocessed using SPM12 software to ensure the quality and reliability of the data. In the preprocessing, a series of steps were used to optimize the functional images as follows: (1) The temporal order between different slices was corrected by temporal layer correction[4] , which eliminated the temporal bias due to the different acquisition order, which is important for the subsequent data analysis because it can ensure the data consistency in time. (2) Head motion correction was performed on the original functional images using least squares and a six-parameter rigid-body spatial transformation[5] . The accuracy of the data was improved by calculating the spatial offset of each voxel and correcting the image artifacts caused by head motion. (3) After head movement correction, two procedures were used to spatially align all images to the mean value of the images[6] . First, all functional images were aligned to the mean functional image to further eliminate the effect of head motion. This step resulted in more accurate functional images and reduced errors due to head motion. Second, the high-resolution T1 structural images are co-aligned with the average functional images (reference images) with the aim of aligning anatomical structural information with functional data to provide anatomical references for subsequent analysis. (4) The co-aligned T1 structural images are segmented using a unified segmentation procedure[7] . By segmenting the T1 structural images into different tissue categories, such as gray matter, white matter and cerebrospinal fluid, more accurate tissue localization information can be obtained to provide accurate anatomical information for the subsequent spatial alignment and analysis. (5) To convert functional images to standard space, we converted the functional images realigned in local space to Montreal Neurological Institute (MNI) space with the aim of comparing data between subjects and aligning with most standard spatial templates.(6) The normalized functional images were resampled with a 3x3mm voxel size and smoothed using a Gaussian kernel with a full half-peak width of 4mm. The smoothing process can effectively reduce the noise and enhance the spatial distribution of the signal, improving the signal-to-noise ratio and statistical efficacy of the data.

2.6 fMRI data analysis

After data preprocessing, the fMRI data were analyzed using the SPM package[8] , a voxel-based statistical method, and the brain was divided into 90 brain regions according to the AAL template[9] , and the activation intensity and clump size were accurately calculated for each brain region, and the results were presented as a trilinear table. The results were visualized using MRIcron, BrainNet to visualize the brain activation regions and the size of the activated regions more visually.

3. Results

3.1 Results of DF and HC when performing the tone II task

Table 1 Results of DF when executing tone two

Brain region	Hemisphere	Cluster	Peak	Peak MNI coordinates(mm)		
				x	y	z
Middle occipital gyrus	L	178	8.37	-28	-100	8
	R	39	7.04	32	-94	12
Pre-central gyrus	L	58	6.90	-50	-2	48
	R	13	5.72	58	4	34
Supplementary motor area	L	128	6.77	-2	-8	60
	R	15	6.00	10	2	74

Note: Brain region represents the name of the activated region; Hemisphere represents the hemisphere where the activated region is located; x, y and z are Montreal Neurological Institute (MNI) brain map coordinates.

Table 2 Results of HC when executing tone II

Brain region	Hemisphere	Cluster	Peak	Peak MNI coordinates(mm)		
				x	y	z
Calcarine	R	1746	9.55	38	-74	-22
Middle occipital gyrus	L	463	8.81	-24	-98	-8
Middle temporal gyrus	R	64	6.88	68	-28	-2
Triangle - Interior frontal gyrus	L	157	7.20	-42	20	24
Pre-central gyrus	L	365	9.40	-36	2	58
Supplementary motor area	L	152	6.92	-4	20	66
Middle frontal gyrus	R	43	6.19	44	4	52
Superior parietal lobe	L	595	10.64	-20	-70	54
	R	311	7.41	26	-68	54

Note: Brain region represents the name of the activated region; Hemisphere represents the hemisphere where the activated region is located; x, y and z are Montreal Neurological Institute (MNI) brain map coordinates.

As seen in the results, the bilateral middle occipital gyrus, bilateral precentral gyrus, and bilateral supplementary motor area brain regions were activated in children with DF during the execution of the vocal tone II task; the right perisylvian cortex, left middle occipital gyrus, right middle temporal gyrus, left inferior deltoid frontal gyrus, left precentral gyrus, left supplementary motor area, right middle frontal gyrus, and bilateral superior parietal gyrus were activated in children with HC.

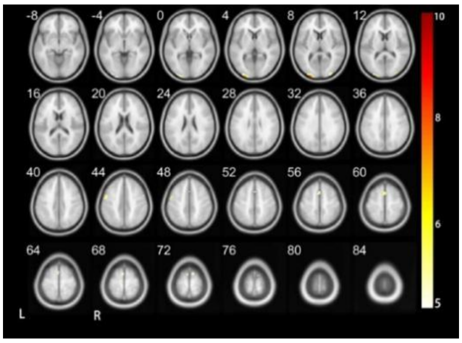

Fig. 1 Results of DF when executing Tone II

3.2 Results of DF and HC when performing the tone four task

Table 3 Results of the execution of the vocal tones four-time DF

Brain region	Hemisphere	Cluster	Peak	Peak MNI coordinates(mm)		
				x	y	z
Middle occipital gyrus	L	125	5.86	-26	-98	-8
Middle temporal gyrus	L	34	6.08	-62	-44	12
Superior temporal gyrus	R	111	6.05	62	-8	6

Note: Brain region represents the name of the activated region; Hemisphere represents the hemisphere where the activated region is located; x, y and z are Montreal Neurological Institute (MNI) brain map coordinates.

Table 4 Results of the implementation of vocal tones four-time HC

Brain region	Hemisphere	Cluster	Peak	Peak MNI coordinates(mm)		
				x	y	z
Interior occipital gyrus	L	99	7.17	-28	-88	-6
Calcarine	L	84	6.98	-14	-98	-6
Superior temporal gyrus	L	75	6.83	-68	-32	12
	R	100	7.40	68	-30	2
Triangle - Interior frontal gyrus	L	125	8.09	-52	30	16
Pre-central gyrus	L	63	6.90	-46	8	48

Note: Brain region represents the name of the activated region; Hemisphere represents the hemisphere where the activated region is located; x, y and z are Montreal Neurological Institute (MNI) brain map coordinates.

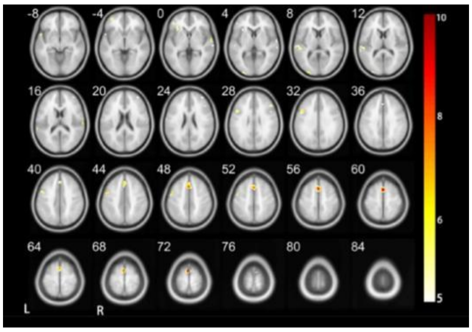

Fig. 2 Results of executing the vocal tones four-time DF

As seen in the results, the left middle occipital gyrus, left middle temporal gyrus and right superior temporal gyrus regions were activated in children with DF and the left medial occipital gyrus, left talar cortex, bilateral superior temporal gyrus, left triangular medial frontal gyrus and left precentral gyrus regions were activated in children with HC when performing the vocal tones IV task.

4. Discussion

4.1 Due to hearing loss, part of the deaf child's brain area that processes vocal tones does not work properly

Related studies have shown[10] that the left inferior frontal gyrus, the right middle temporal gyrus and the bilateral superior temporal gyrus are key regions in the neural correlates of tone perception. However, in the comparison of tone II, no activation was found in the superior parietal and superior frontal gyrus in DF children compared to HC children. The inferior frontal gyrus, middle frontal gyrus and parietal regions have important roles in human behavior and cognition, including emotion, memory, cognitive control and auditory perception[11,12] . The results suggest that these brain areas fail to function properly in deaf children compared to normal children, possibly due to hearing loss, and they are unable to learn to recognize vocal tones through the auditory system. Deaf children usually rely on gestures such as sign language or oral language to communicate, unlike normal children who receive speech information directly through auditory input to learn and recognize vocal tones .[13]

4.2 Deaf children may rely on different neural networks when processing vocal tone information

Because they cannot receive speech information directly through auditory input, deaf children may need to devote additional cognitive resources and attention to the processing of vocal tones, which results in the activation of additional brain regions. In contrast, normal children have already formed corresponding neural networks and cognitive patterns during speech learning and perception, and therefore show more efficient brain activity patterns in the tone discrimination task. The above results, in which the activation clump size was significantly larger in normal children than in deaf children, also confirmed our conjecture. Moreover, a previous study found that[14] ,deaf patients had significant activation of auditory centers in response to visual stimuli. After our comparison, we found that the activity of regions such as the superior temporal gyrus was stronger in deaf children in the third tone recognition task, suggesting that deaf children may use visual information instead of auditory information to process tones[15] , requiring more brain regions to process this task.

4.3 Children with hearing impairment process vocal tone information with hemispheric characteristics

A previous study showed that tones and segments can be processed in parallel in the left and right hemispheres, but the product of their integration or integration is located in the left hemisphere.

In addition, our study found that children with hearing loss exhibit hemispheric characteristics when processing vocal tone information. That is, unlike normal children, the corresponding brain hemisphere is activated when processing specific vocal tones. Specifically, in the tone II results, children with hearing loss showed significant activation in the bilateral middle occipital gyrus, bilateral precentral gyrus, and bilateral supplementary motor areas compared to normal children; in addition, in the tone IV results, deaf children showed more significant activation in the right hemisphere superior temporal gyrus region compared to normal children who showed bilateral activation.

Summary

Our study discusses the neural mechanisms underlying vocal tone recognition in deaf children. Our findings suggest that deaf children may rely on different neural networks to process vocal tone information compared to hearing children, and that the main activation differences between the two in vocal tone processing tasks are found in the middle occipital gyrus, precentral gyrus, superior temporal gyrus, and supplementary motor regions. In contrast to previous studies, we found that deaf children may rely on other information for processing and processing vocal tone information. The study only discussed the neural mechanisms of vocal tone recognition in deaf children for the second and fourth, and further studies are needed to confirm the findings.

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