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Functional Magnetic Resonance Imaging (fMRI) Study of Short-Term Memory Changes After Congenital Heart Surgery in Children

Kaihua Jiang[1]*, Wei Zhang[1]#, Wanchao Zhang[2]#, Yunzhi Ling[1], Sudan Deng[1], Yanshu Ding[1], Yanling Wu[1]

[1]*Department of Pediatrics, Affiliated Changzhou Children's Hospital of Nantong University, Changzhou, China.*
[2]*Department of Radiology, The people's hospital of Wu Qia County, Wu Qia, China.*
**Corresponding author: Kaihua Jiang.*
#Wei Zhang and Wanchao Zhang contributed to the work equally to this study and should be regarded as co-first authors.

Abstract

Objective: To explore the behavioral characteristics and brain mechanism of short-term memory changes in children with congenital heart disease before and after operation.

Methods: Twenty children aged 6-9 was tested with functional magnetic resonance imaging (fMRI) and short-term memory behavior 1 week before and 2 weeks after operation, and the data before and after operation were analyzed by paired t-test.

Results: The values of ALFF after operation in left inferior temporal gyrus, middle temporal gyrus, right superior temporal gyrus and bilateral anterior cingulate gyrus were lower than those before operation, and the correct rate of short-term memory after operation was lower than that before operation. The ALFF values of bilateral anterior cingulate gyrus and right superior temporal gyrus were positively correlated with the correct rate of active memory tasks.

Conclusion: Congenital heart surgery in children has an effect on children's short-term memory, which is mainly related to the temporal lobe and anterior cingulate gyrus.

Keywords: congenital heart disease; short-term memory; functional magnetic resonance imaging; children

Introduction

Postoperative cognitive dysfunction (POCD) is a common complication of central nervous system in patients after operation, such as memory impairment, decreased attention, decreased information processing ability and so on [1]. Among them, the incidence of postoperative neurological complications in children is as high as 42%-67% [2], but there is a lack of scientific evaluation methods. At present, consultation and scale are often used for evaluation, but these methods fail to quantify the degree of POCD, which affects the timeliness of clinical intervention.

Functional magnetic resonance imaging (fMRI) is a new technique for the study of children's cognition in recent years, which has the advantages of high spatial resolution and non-invasive [3,4]. Resting state (rs-) fMRI eliminates the interference of tasks on the results, and the results are objective, real and repeatable [5]. Amplitude of low frequency fluctuation (ALFF) can detect the local intensity of blood oxygen level-dependent signals produced by spontaneous brain activity, and is an objective index to reflect the level of local brain activity [6]. The purpose of this study is to explore the fMRI indexes of short-term memory changes in children with congenital heart disease before and after operation through the combination of fMRI and behavior.

Participants and methods

Participants

Twenty children with congenital heart disease were diagnosed by pediatric cardiac specialist clinic in our hospital, including atrial septal defect and ventricular septal defect, aged from 6 to 9 years old, 11 males and 9 females, with an average of 7.07 ±0.80 years old. There were no basic diseases such as bronchiectasis, airway malformation and other basic diseases affecting cardiopulmonary function; Raven's standard reasoning test ≥ 80; right-handed. No neuropsychiatric symptoms, signs and medical history; able to tolerate MRI examination. In this study, approved by the Ethics Committee of

Changzhou Children's Hospital (2022-L001), all subjects have signed informed consent forms.

Methods

fMRI and short-term memory behavior tests were performed one week before and 2 weeks after operation in children with congenital heart disease. fMRI method: the functional imaging data were collected by Siemens Auto1.5T magnetic resonance machine. Children lie flat on the examination table, keep their eyes closed and awake, and breathe calmly. fMRI data acquisition uses single-shot plane echo sequence (EPI) to obtain 18 layers of T2-weighted data, parameters include: TR=2000ms, TE=40ms, flip angle = 90°, field of view (FOV) = 24cm × 24cm, matrix = 64 × 64, layer thickness = 6.0mm, spacing = 1.2mm, scanning time 360s [7].

The short-term memory paradigm adopts the active memory task developed by Professor Zhou of Nanjing University [8]. It is a classical paradigm used to study refresh function. The children were presented with strings of English letters of different lengths in turn, and the children were required to always remember the three capital letters that appeared recently. When the letter string was presented, three capital letters were presented at the same time, and the subjects were asked to judge whether the three capital letters were the last three letters in the string. If the letters and the order of the letters can correspond one to one, press the F key on the keyboard; if the letters correspond but the order does not correspond or the order corresponds to the letters, press the J key. In the test program, the length of the letter string is uncertain, and the length range of the letter string is 410. The difficulty of the task is changed by changing the length of the letter string. The longer the length of the letter string is, the more difficult the task is. The level of short-term memory was evaluated by recording the correct rate of judgment.

Data preprocessing

The rs-fMRI data processing software DPARSF (Data Processing Assistant for Resting-State fMRI) [9] was used for batch processing of fMRI data and other related post-analysis. The processing process includes: converting the original DICOM data into NIFTI format, removing the first 10 time points, thus eliminating the effects of uneven magnetic field and subjects not adapting to the environment at the beginning of scanning, and continuing time and space alignment and head movement correction at the remaining 170 time points. The subjects whose head movement distance > 3mm and rotation angle > 3° were excluded, and the data of children in this study were not removed. Then 3mm resampling is used to normalize each avatar into the Montreal Institute (MNI) standard space, and FWHM is used as the Gaussian kernel function of 6mm for smoothing.

ALFF calculation

The ALFF principle is to use the fast Fourier transform algorithm to convert the time domain signal to the frequency domain to get the power spectrum, and the square root of the power spectrum is the ALFF value [10]. The ALFF is analyzed by REST (http://www.restfmri.net) software. The processing process includes filtering the preprocessed image ($0.01<f<0.08$Hz) to eliminate the low frequency drift and high frequency physiological respiratory and heartbeat noise, while removing the linear drift, and then calculate the ALFF. In order to improve the normality of data, Fisher transform is used to convert the correlation coefficient into Z value.

Statistical processing

The paired t-test was performed on the standardized ALFF encephalogram of children before and after congenital heart surgery with REST software. The threshold was set to $P < 0.001$ (before correction). At the same time, only the regions with no less than 13 continuous voxels were considered to be statistically significant ($P<0.05$ after Alpshasim correction). The results of paired t-test were superimposed on the Ch2 template, and the correct rate of short-term memory before and after operation was compared. Finally, the correlation between ALFF and correct rate was analyzed.

Results

The correct rate of short-term memory after congenital heart surgery in children (0.816±0.042) was lower than that before operation (0.873±0.078). The difference was statistically significant ($P=0.041$, $t=-2.338$).

The value of ALFF after congenital heart surgery was lower than that in the brain areas before operation, including left inferior temporal gyrus, middle temporal gyrus, right superior temporal gyrus and

bilateral anterior cingulate gyrus (see Table 1, figure 1).

Table 1: The comparison of ALFF before and after congenital heart surgery

Brain regions	Voxels (mm^3)	Brodman's area	MNI coordinates			T Value
left inferior temporal gyrus, middle temporal gyrus	27	20	-51	-21	-24	-7.52
left inferior temporal gyrus	80	37	-36	-36	-3	-6.30
right superior temporal gyrus	84	37	33	-42	-6	-6.37
right anterior cingulate gyrus	104	-	21	27	6	-6.85
left anterior cingulate gyrus	372	-	-12	-9	45	-7.79
right anterior cingulate gyrus	42	-	27	-24	45	-6.91

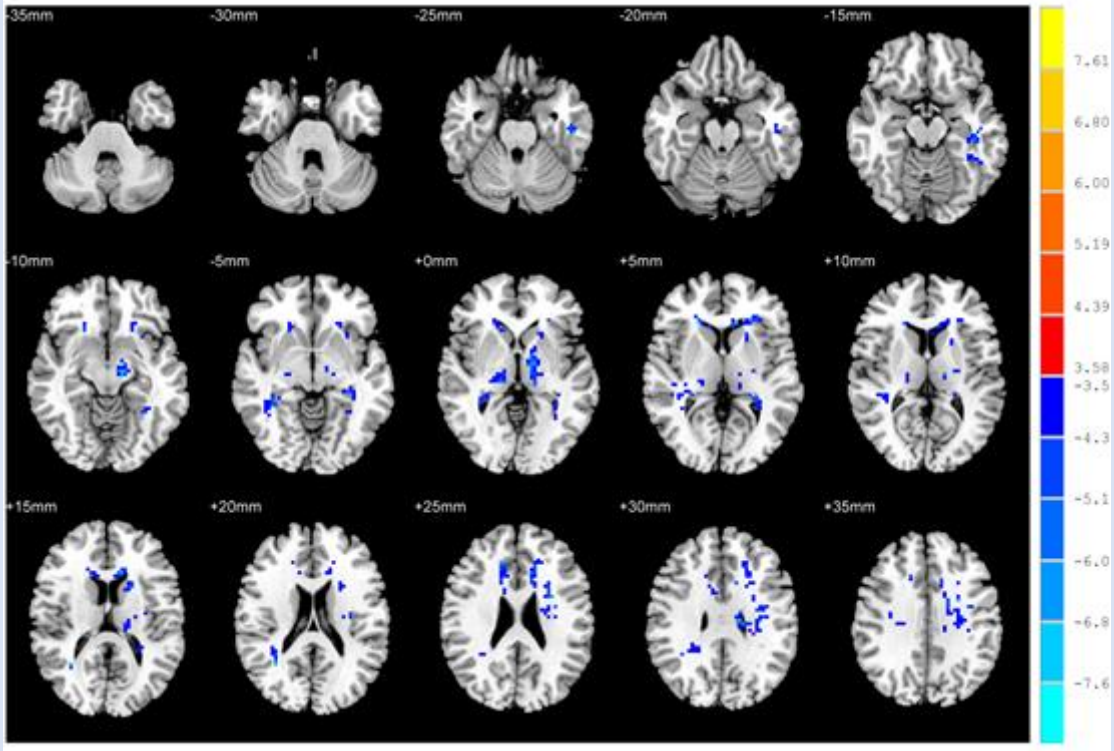

Figure 1: The brain regions with comparison of ALFF before and after congenital heart surgery.

Note: The blue areas showed the brain regions where the ALFF value after surgery was lower than that before surgery.

The results of correlation analysis between ALFF values of the 6 brain regions above and the accuracy of active memory tasks were as follows: r=0.282, P=0.204 (left inferior temporal gyrus, middle temporal gyrus); r=0.389, P=0.073 (left inferior temporal gyrus); r=0.428, P=0.047 (right superior temporal gyrus); r=0.413, P=0.056 (right anterior cingulate gyrus); r=0.502, P=0.017 (left anterior cingulate gyrus); r=0.512, P=0.015 (right anterior cingulate gyrus). The ALFF values of bilateral anterior cingulate gyrus and right superior temporal gyrus were positively correlated with the accuracy of active memory tasks.

Discussion

ALFF measures the amplitude of fluctuations in the low-frequency range (usually 0.01~0.08Hz) of fMRI signals, reflecting spontaneous neural activity in the brain. In this study, it was found that the brain regions with lower ALFF values after congenital heart surgery were mainly located in temporal lobe and anterior cingulate gyrus, and the correct rate of short-term memory after congenital heart surgery was lower than that before operation. ALFF values in multiple brain regions of temporal lobe and anterior cingulate gyrus were significantly correlated with short-term memory behavior.

Temporal lobe is related to memory, association, comparison and other advanced neural activities, temporal lobe lesions will appear different forms of

memory dysfunction [11]. The temporal lobe communicates with the hippocampus and plays a key role in the formation of explicit memory regulated by the amygdala [12]. Memory impairment may occur when the temporal lobe is destroyed, usually when bilateral damage occurs, and memory impairment may be accompanied by disorientation [13]. In this study, it was found that the ALFF values of left inferior temporal gyrus, middle temporal gyrus and right superior temporal gyrus after congenital heart surgery were lower than those before operation, and the ALFF of right superior temporal gyrus was positively correlated with the correct rate of short-term memory. It is suggested that the function of the temporal lobe is decreased and the short-term memory is damaged by congenital heart surgery in children.

The feature representation of anterior cingulate gyrus initiates the extraction of memory [14]. There is a functional connection between the anterior cingulate gyrus and the orbitofrontal cortex and provides reward reflection for memory and target navigation [15]; the effective connection of the anterior cingulate gyrus points directly to the hippocampal system, which provides a way for reward-related information to enter the hippocampal system, provide part of the hippocampal episodic memory system for value-related and emotional information, and further provide navigation targets [16]. This study found that the ALFF value of bilateral anterior cingulate gyrus after congenital heart surgery was lower than that before operation, and it was significantly correlated with the behavioral accuracy of short-term memory, suggesting that congenital heart surgery damaged the function of anterior cingulate gyrus in children, thus affecting the function of short-term memory.

Conclusion

In this study, through the comparison of ALFF before and after operation in children with congenital heart disease, and the correlation analysis with short-term memory behavior, we explored the brain mechanism of short-term memory decline after congenital heart surgery in children, and found that it was mainly related to the impairment of temporal lobe and anterior cingulate gyrus. It is very difficult to collect fMRI and behavioral data before and after congenital heart surgery in children, so the amount of data in this study is relatively small. In the future, we will continue to expand the sample size and study combined with brain structure, so as to have a more comprehensive understanding of the brain mechanism of cognitive changes before and after cardiac surgery in children.

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