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Research article

The influence of positive emotion and negative emotion on false memory based on EEG signal analysis

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ABSTRACT

Analyzing the influence of emotion on false memory through electroencephalogram is helpful to further explore the cognition function of brain. In this study, material emotion and participant emotion were introduced into Deese-Roediger-McDermott (DRM) paradigm experiment at the same time, which made the experiment process closer to real life. Different music was used to induce the emotion of 28 participants, and they were divided into positive group and negative group. Then, we analyzed the difference between the two groups from the behavior data, source location and cortex functional network of event related potential. The results of difference analysis show that the false memory rate of positive group (85 ± 8.6%) is significantly higher than that of negative group (72 ± 9.7%), and the activation degree and voxel number of the positive group are significantly higher than those of the negative group in the brain regions related to semantic coding (BA24 and BA45), and the compactness, the speed of information transmission and the small-world property of the brain network in positive group are significantly higher than those in negative group. The above results show that in the positive group, more brain resources are used for semantic association when they judge keywords, which confuse the keywords and learning words, and result in more false memories.

1. Introduction

Since the 19th century, the relationship between emotion and memory has been one of the focuses of social cognitive neuroscience. With the development of research on the influence of emotion on correct memory, many scholars began to study the relationship between emotion and false memory. False memory is a common phenomenon in life [1,2]. Some researchers asked participants to memorize emotional vocabulary in the neutral emotional state. They found that participants had more false memories of words with negative emotions than words with positive emotions [3,4]. Some researchers used neutral vocabulary to study the influence of participants' emotional state on false memory, and found that participants in positive emotional state produced more false memories than those in negative emotional state [5,6]. It can be found that in the past, most researches on false memory are based on behavioral data or psychological analysis.

With the development of science and technology, in recent years, more and more scholars began to use advanced instruments or technologies to conduct more in-depth research on false memory. In these studies, many researchers have studied false memory by collecting participants' electroencephalogram (EEG) signals. Among them, Chen et al. found that the test context had effects on false memory rate and event-related potential (ERP) of false memory from 300 to 600 ms [7]. Morcom found between 500 and 800 ms post-stimulus, ERPs for correctly recognized studied pictures and falsely recognized lures compared to those for correctly rejected novel items had a left centroparietal scalp distribution [8]. Zheng et al. found that compared with positive and neutral emotional pictures, negative emotional pictures enhanced the old and new effects of parietal lobe related to recall, so they produced less false memory [9]. Volz et al. found that the amplitudes of ERP late components of correct memory and false memory were different in frontal lobe [10]. Favre et al. found that the amplitudes of P2 and N400 of false memory ERP in psychiatric patients were smaller than those in healthy controls [11]. We can find that in most EEG studies related to false memory, material emotion and participant emotion are not introduced into the experiment at the same time. But in real life,

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people's emotions when they learn or memorize will change spontaneously or affected by external factors, and the emotions of the memory materials that people face will also change.

As a typical bioelectrical signal, EEG signal contains a lot of pathological or physiological information. The study of EEG signal can not only diagnose some brain diseases clinically, but also help us to explore the working mechanism of brain essentially under non-invasive conditions. The EEG signals collected on the scalp have high time resolution, but the interference caused by scalp, skull and cerebrospinal fluid is inevitable. Therefore, estimating the position and intensity of neural activity sources in the brain based on the EEG signals recorded on the scalp can help us understand the working mechanism of the brain more accurately [12]. By combining complex networks with brain neuroscience, we can study the cognitive activities of the brain in time domain or frequency domain through some attributes of brain networks. In recent years, the construction and analysis of brain function network has been widely used in the research of mental disease, neurological disease, behavioral disorder and other brain diseases [13,14]. However, the spatial resolution of brain network directly established by scalp EEG signal is low and has the effect of cranial cavity volume effect. Therefore, some researchers reconstruct the source from the scalp EEG signals firstly, map the localization to the cortex, and then construct the functional network of cortex. This method improves the spatial–temporal resolution and makes the constructed brain network more reliable [15,16].

DRM paradigm experiment can well induce participants' false memory and record it [17]. In this study, we introduced two emotional factors that affect memory into the experiment at the same time, and collected the participants' EEG signals. By comparing the source localization results of ERP of false memory and the attributes of functional network of cortex, we analyzed the influence of participants' emotional state on false memory in DRM paradigm experiment with mixed emotional memory materials. This study provides a theoretical basis for how to avoid the occurrence of false memory in life and to study the working mechanism of brain memory.

2. Materials and methods

2.1. Experimental

In this study, E-Prime 3.0 software was used to design the experimental interface and record the behavior data of participants in the background. Neuroscan equipment was used to collect 64 channel EEG signals. The distribution of electrode channels conformed to the international 10–20 electrode lead positioning standard. The sampling frequency was 1 kHz. The impedance between the electrode and the scalp was kept below 10 kΩ.

Twenty-eight 22 to 25 years old graduate students participated in the experiment. The participants were chosen as right-handed, native Chinese speakers, with no history of mood disorders and depression. Participants were randomly assigned to positive or negative mood conditions. The participants' emotions were evoked by music. Participants in the positive group listened to 3 min of Bach's *Brandenburg Concerto No. 3* and participants in the negative group listened to 3 min of Prokofiev's *Alexander Nevsky: Russia Under the Mongolian Yoke*. No ethical issues were involved in the experiment, and the study conformed to the Declaration of Helsinki. All participants signed the informed consent before the experiment.

We had improved the experimental materials and experimental flow in the traditional DRM paradigm, so that the experimental includes two emotional factors: material emotion and participant emotion. In our experimental materials, 12 emotional word lists (four positive, four neutral, four negative) were mixed and used. Each word list contained 12 learning words (all of them appeared in the learning phase, some of them appeared in the test phase) and 1 keyword was used to induce false memory (it only appeared in the test phase to induce false memories). In the learning phase, the lists were mixed and presented to the participants. In the test phase, the error rate of these keywords was the false memory rate of participants. The participants' emotions were fully induced before the learn stage and the test stage, and then verified by positive and negative affect schedule (PANAS). During the learning phase, each word was displayed on the computer monitor for 1 s, and the word needs to be remembered by the participants. During the test phase, each word was displayed on the computer monitor for 2 s. If the participants think they had seen the word in the learning phase, they were asked to press the "F" key on the keyboard, and otherwise press the "J" key. If the participant did not press the key after 2 s, it would automatically enter the next interface. The responses without keystroke had no research significance in this study, so they were deleted. The flow of the whole experiment is shown in Fig. 1.

2.2. Source location

After preprocessing the collected EEG signals, we superposed and averaged the EEG signals of false memory, and obtained the ERP of participants' false memory. We used standard low resolution brain electromagnetic tomography algorithm (sLORETA) to locate the source of ERP. The sLORETA is a linear source localization algorithm proposed by Pascal-Marqui [18]. When sLORETA is used to locate the source of EEG signal, the spatial resolution will decrease with the increase of depth, but the linear characteristic of the algorithm will make the error of the source position be zero in the ideal case [19]. At present, it has been widely used in the detection of Alzheimer's disease, epilepsy, depression and other brain diseases [20,21]. A real head boundary element model was used. The distance between voxels in the head model was 2.5 mm, and the source localization results were constrained on the cerebral cortex. The distribution of current density on the cerebral cortex can be obtained.

2.3. Cortex functional network

To construct a cortex functional network, the nodes and edges must be determined first. According to the 64 channels on the electrode cap, we defined 64 regions of interest (ROI) in the cerebral cortex, and took the center of these regions as the node. The location of 64 ROI nodes is shown in Fig. 2.

The degree of association between two nodes in the network is the connection edge. We used sLORETA to locate the source of the EEG signals. Finally, we get 31,061 voxel points per millisecond in the cerebral cortex, and each voxel point has a corresponding current density value. We redistributed the current density values of 31,061 voxel points to 64 ROI nodes according to the principle of proximity, and obtained the current density values of 64 ROI nodes per millisecond. The correlation matrix of brain network can be constructed by using the current density value of ROI node. We used the Pearson cross correlation algorithm to calculate the degree of association between every two ROI nodes, and got the 64 × 64 correlation matrix.

The appropriate threshold was selected to binarize the correlation matrix, and then the brain network was constructed by using the binary matrix. When selecting the threshold, we should not only ensure the integrity of the network, but also avoid the network being too dense, and at the same time ensure the small-world property of the network. In order to ensure the reliability and comparability of binary matrix, we started from 1 and tested the threshold by decreasing 0.01 every time. The results showed that when the threshold was $T = 0.85$, the brain network of the three groups had good integrity.

2.4. Brain network analysis method

We analyzed the topological structure of the cortical functional network from the node degree, clustering coefficient, global efficiency and small-world property [22].

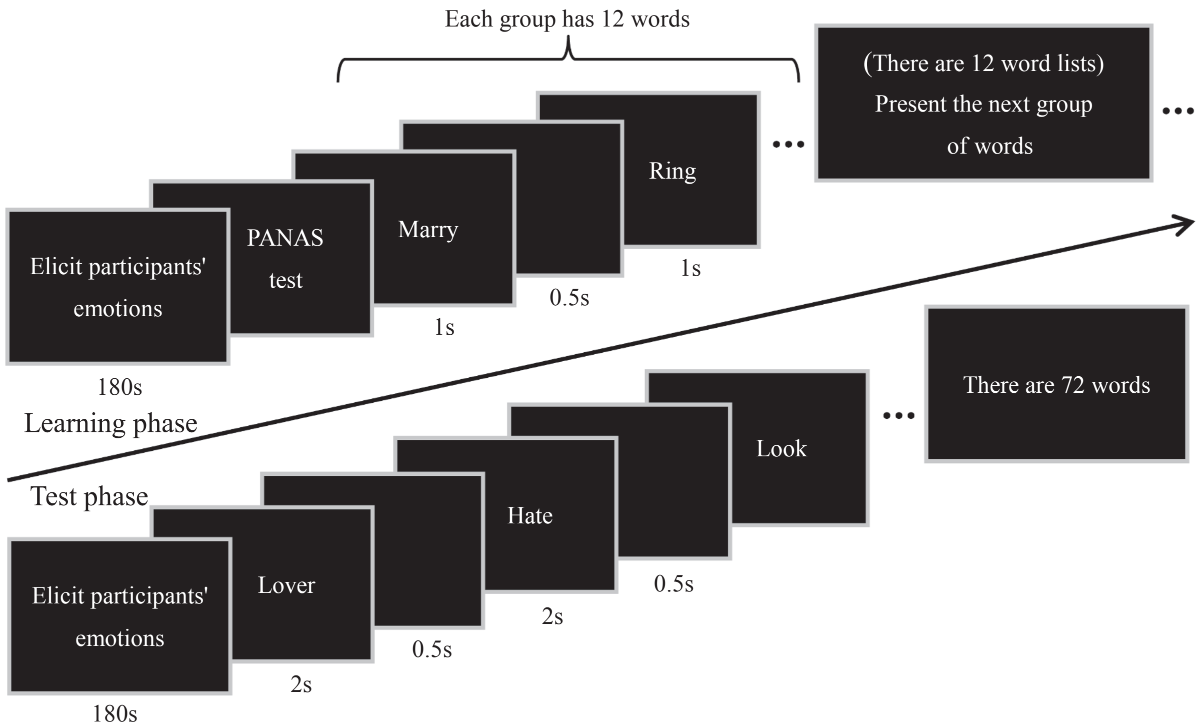


Fig. 1. Schematic diagram of experiment flow.

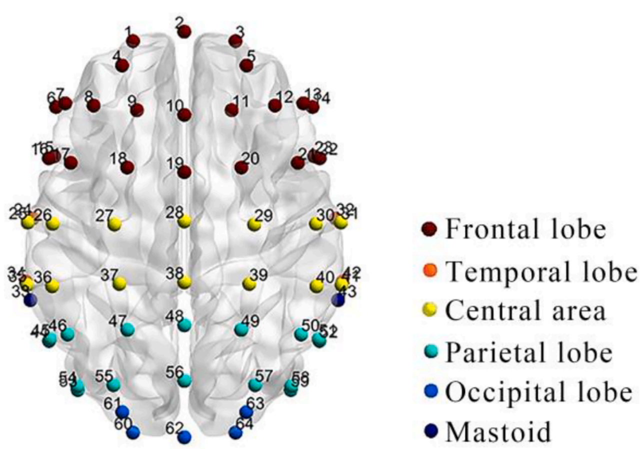


Fig. 2. Location of 64 ROI nodes in cerebral cortex.

2.4.1. Node degree

In the network, the node degree represents the total number of nodes connected with node i, which is a basic measurement index in complex networks. The greater the degree of nodes, the more connected edges and the more important it is in the network. The calculation formula of node degree is as follows:

$$k_i = \sum_{j=1}^{N} \boldsymbol{A}_{ij} \tag{1}$$

where N is the total number of network nodes, $\boldsymbol{A}_{ij}$ is the element in the binary matrix.

2.4.2. Clustering coefficient

In the network, the clustering coefficient represents the probability of interconnection between neighbors of node i. It is used to measure the clustering characteristics and compactness of the network, and can reflect the connectivity of brain functional network. The clustering coefficient of the whole network is represented by the average value of clustering coefficient of all nodes in the network. The average clustering coefficient C ranges from 0 to 1, and the larger its value, the closer the connection between brain network nodes. The calculation formula of average clustering coefficient is as follows:

$$C = \frac{1}{N}\sum_{i=1}^{N} C_i = \frac{1}{N}\sum_{i=1}^{N}\frac{2e_i}{k_i(k_i-1)} \tag{2}$$

where e_i is the number of connection edges actually existing between neighbor nodes of node i, $k_i(k_i-1)/2$ is the number of possible connection edges between neighbor nodes.

2.4.3. Global efficiency

Global efficiency can be used to measure the global transmission capacity of brain network. The global efficiency is directly proportional to the information transmission rate between nodes. The calculation formula of global efficiency is as follows:

$$E_{\text{global}} = \frac{1}{N(N-1)}\sum_{i,j\in V, i\neq j}\frac{1}{l_{ij}} \tag{3}$$

where V is the set of all nodes, N is the total number of network nodes, l_{ij} is the number of edges when node i and node j are connected with the least number of edges.

2.4.4. Small-world property

Small-world network represents a network with high clustering coefficient and shortest path length. Small-world property σ of the network can be quantitatively analyzed, and its description is as follows:

$$\sigma = \frac{\gamma}{\lambda} = \frac{C/C_{\text{random}}}{L/L_{\text{random}}} \tag{4}$$

where C is the average clustering coefficient of the network, C_{random} is the clustering coefficient of a random network with the same number of nodes and edges as the network, L is the average path length of the network, L_{random} is the path length of a random network with the same number of nodes and edges as the network.

When $\sigma > 1$, it means that the network has small-world property, and the larger the value of σ, the stronger the small-world property of the network.

3. Results

3.1. Behavioral data

We counted the participants' PANAS score and the number of false memory keystrokes, and then used spss20.0 software to conduct an independent sample *t*-test on them. The statistical results of PANAS showed that the score of positive questions in the positive group was significantly higher than that in the negative group ($p = 0.000 < 0.05$), and the score of positive questions in the negative group was significantly lower than that in the negative group ($p = 1 \times 10^{-6} < 0.05$), which indicated that music successfully induced the emotion of the two groups. The statistical results of keystroke showed that the false memory rates of the positive group and the negative group were $85 \pm 8.6\%$ and $72 \pm 9.7\%$, respectively. And the false memory rate of the positive group was significantly higher than that of the negative group ($p = 3 \times 10^{-3} < 0.05$).

3.2. Source location

By analyzing the ERP of 0–1 000 ms after stimulation, we found that there was a great difference in the late ERP components between the positive group and the negative group. The peak current density of positive group and negative group appeared at 474 ms and 820 ms after stimulation, respectively. The current density at the peak point of the two groups was significantly different. In order to avoid the influence of other bands on the source location, we use the peak time as the zero point, select the ERP from –100 to 100 ms to intercept the error memory ERP again, and study the source location of the current density peak point. The source localization results are shown in Fig. 3. By analyzing the source localization results, we find that the positive group is mainly located in the frontal and temporal lobes (see Fig. 3(a)). The negative group is mainly located in the prefrontal and right temporal lobes (see Fig. 3(b)). Combined with the behavioral data, we find that the positive group has higher activation intensity and more false memories. The negative group has lower activation intensity and less false memories. The results show that the more active the brain is, and the more false memories are produced when identifying keywords.

In order to study the difference of source localization more accurately, we used the statistical nonparametric mapping (SnPM) method [23] to make the difference statistics of the coordinates of voxels after source localization between the two groups. Then, the source localization and current density difference analysis of these voxels are carried out with Curry8 software. The location of the difference voxels is shown in Fig. 4. The eighteen small images in Fig. 4 are transverse slices of the cerebral cortex. The statistical comparison of source current density is shown in Table 1. The F-value in Table 1 represents the current density value, and the Talairach coordinate is the voxel point coordinate with the largest F-value in voxels. It can be seen from Fig. 4 and Table 1 that BA24 (marginal cingulate gyrus) contains the largest number of differential voxels, which indicate that the difference in the activation range of BA24 is the most obvious. The F-value of BA45 (inferior frontal gyrus) has the biggest difference, which indicate that the difference of activation intensity in BA45 is the most obvious.

3.3. Cortex functional network

3.3.1. Network construction results

The binary correlation matrixes of positive group and negative group are shown in Fig. 5. The blue square is 0, indicating no connection. The yellow square is 1, indicating that there is a connection. It can be seen that the positive group has more connecting edges than the negative group.

Fig. 6 shows the cortex functional network constructed by binary matrix. Through the comparison, it can be found that the connecting edge of the positive group is inclined to the left hemisphere of the brain, and the number of connection edges is more than that of the negative group. The connecting edge of the negative group is inclined to the right hemisphere of the brain, and most of the connections are concentrated in the frontal lobe. It shows that different emotional states have a significant impact on the functional connectivity of the participants' brains.

3.3.2. Attribute analysis of the cortex network

In order to further analyze the difference between the two groups, we used Pajek 1.0 software to analyze their cortex functional network attributes.

1) Node degree

We used SPSS 20.0 statistical software to conduct independent sample *t*-test on the node degree of two groups, as shown in Table 2. In Table 2, t is the test statistic, sig.(2-tailed) is the significant two tailed *p* value, df is the degree of freedom, Std. Error Difference is the standard deviation of the mean difference of two samples. In addition, the average node degree of positive group and negative group are 16.750 and 10.563, respectively. The results show that the node degree of positive group is significantly higher than that of negative group ($p = 1.5 \times 10^{-5} < 0.05$). It shows that positive emotions stimulate more connections between nodes, which make more information transmitted between

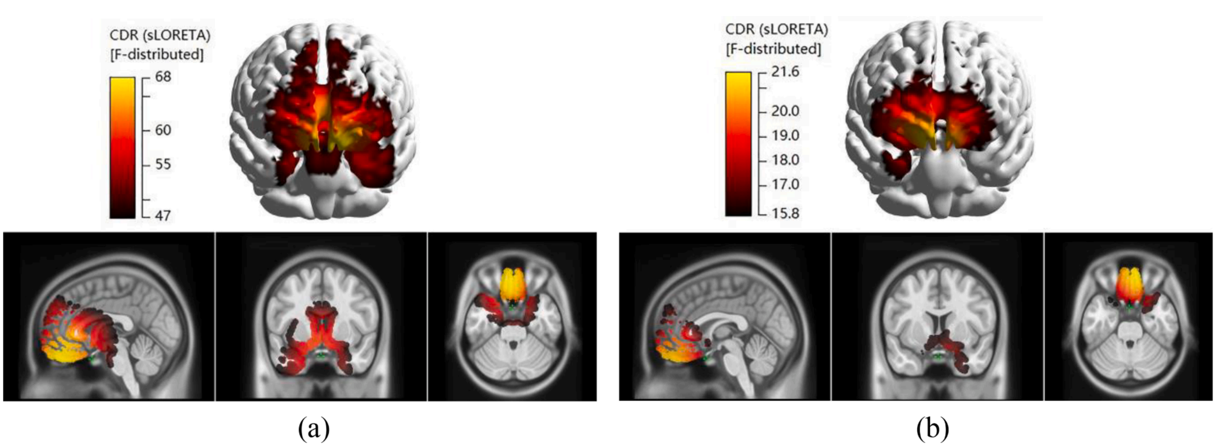


Fig. 3. Source location results (a) Positive group (b) Negative group.

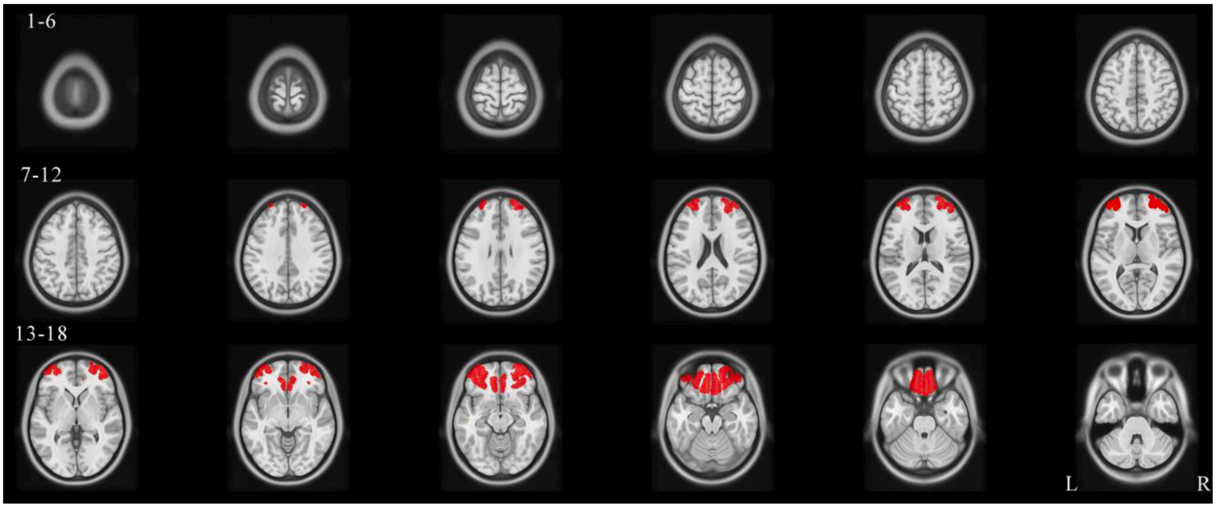


Fig. 4. The location of the difference voxels between the positive and negative groups.

Table 1
Statistical comparison of source current density difference between positive group and negative group.

BA area	Brain area	The number of voxels	Maximum F-value of voxel	Talairach coordinate/mm		
				x	*y*	*z*
BA9	Medial Frontal Gyrus	57	27.72	−34.44	32.17	21.79
BA10	Middle Frontal Gyrus	27	32.43	−35.36	34.77	22.11
BA24	Cingulate Gyrus	107	22.37	13.48	3.96	29.65
BA38	Superior temporal gyrus	43	22.54	−50.21	1.88	−6.21
BA45	Inferior Frontal Gyrus	29	33.63	−40.17	19.95	10.35
BA46	Middle Frontal Gyrus	84	23.76	32.13	31.4	12.75

nodes, whereas less connections between nodes in negative emotional state.

2) Clustering coefficient

The independent sample *t*-test results of clustering coefficients are shown in Table 2. In addition, the average clustering coefficient of positive group and negative group are 0.746 and 0.596, respectively. The results show that the clustering coefficient of positive group is significantly higher than that of negative group ($p = 2.72 \times 10^{-4} < 0.05$). It shows that the brain network of the positive group is closer and more collectivized than that of the negative group.

3) Global efficiency

The independent sample *t*-test results of global efficiency are shown in Table 2. In addition, the global efficiencies of positive group and negative group are 0.542 and 0.420, respectively. Through the analysis, we can find that the average global efficiency of the positive group is significantly higher than that of the negative group ($p = 7.44 \times 10^{-4} < 0.05$). It shows that the information transmission rate of the positive group is significantly higher than that of the negative group.

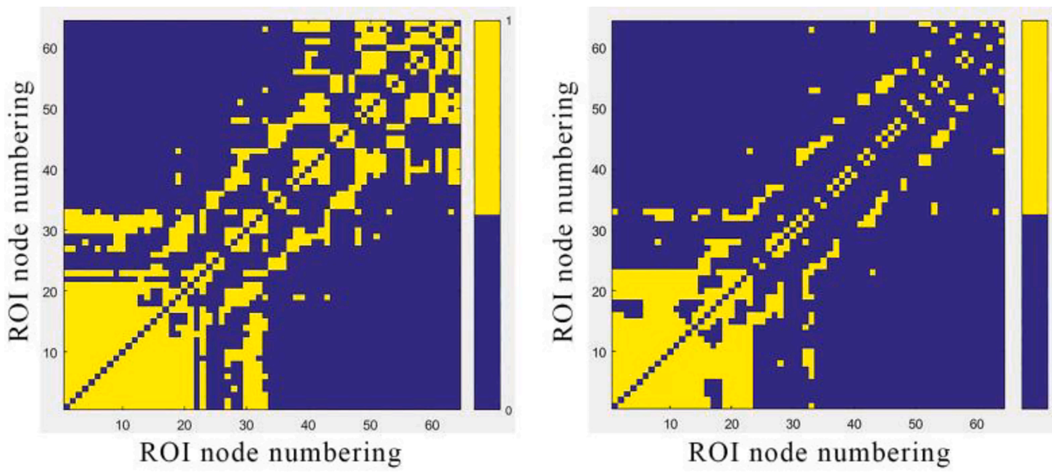
4) Small-world property

The independent sample *t*-test results of σ value are shown in Table 2. In addition, the average σ values of positive group and negative group are 2.294 and 1.765, respectively. It can be seen that the σ value of two groups are greater than 1, which indicate that the brain networks of both groups have small-world property. Through the analysis, we can find that the σ value of the positive group is significantly higher than that of the negative group ($p = 1.00 \times 10^{-6} < 0.05$). It shows that the small-world property of positive group is significantly greater than that of negative group.

4. Discussion

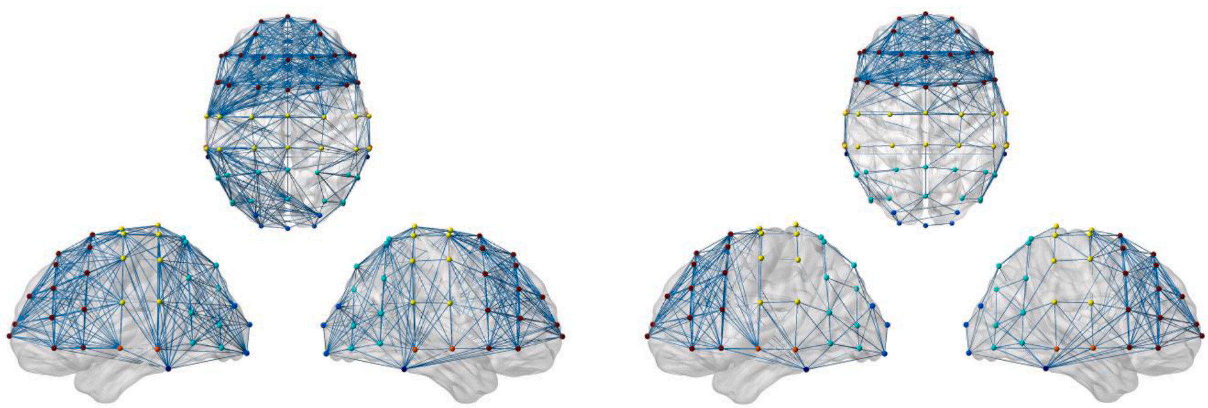
Through the analysis of behavioral data, we found that under the influence of mixed emotional factors, the incidence of false memory in the positive group was significantly higher than that in the negative group. After the source localization of false memory ERP by sLORETA, we found that the difference of source current density between positive group and negative group was mainly reflected in BA24 (marginal cingulate gyrus) and BA45 (inferior frontal gyrus). According to the neurophysiology researches, BA24 is located in the ventral ganglia of cingulate cortex, which is a part of limbic system. It is connected with amygdala, orbitofrontal cortex and hippocampus, and participates in the emotional system of the brain [24,25]. BA45, a part of Broca's area, is located in the frontal cortex and is responsible for semantic tasks and word production [26]. Therefore, we can know that in the identification of keywords, positive emotion prompted participants to stimulate more brain resources, emotional brain areas and semantic brain areas were activated at the same time, which increased the participants' semantic association of keywords. However, negative emotion inhibited the participants to stimulate brain resources, and the activation location was mainly in emotional brain area, which reduced the participants' semantic association of keywords.

After constructing the cortex functional network for ERP of false memory, we found that the connective edges of two groups were mainly concentrated in frontal lobe, but the number of connective edges in positive group was more than that in negative group. The frontal lobe is mainly responsible for working memory, information integration and logical reasoning in the brain [27]. The results of network attribute analysis showed that the important information contained in the nodes in the positive group was significantly greater than that in the negative group. The density of brain network, the rate of information transmission and the nature of small world in positive group were also significantly higher than those in negative group. It showed that the participants in the positive emotion state used more brain resources to integrate the information or logical conjecture between the words seen in the learn stage and the words in the deep memory of the brain.



(a) (b)

Fig. 5. Correlation matrix binary graph (a) Positive group (b) Negative group.



(a) (b)

Fig. 6. Cortex functional network (a) Positive group (b) Negative group. From left to right are left view, top view and right view.

Table 2
Independent sample *t*-test results of cortex functional network attributes in positive group and negative group.

Attribute	t	df	Sig.(2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Node degree	4.510	123.546	1.50×10^{-5}	6.188	1.372	3.472	8.903
Clustering coefficient	3.786	92.536	2.72×10^{-4}	0.150	0.040	0.071	0.228
Global efficiency	3.966	20.292	7.44×10^{-4}	0.122	0.031	0.058	0.186
Small-world property	9.440	36.131	1.00×10^{-6}	0.529	0.056	0.416	0.643

5. Conclusions

In this study, memory materials with mixed emotions were used to design false memory experiments. The influence of participants' emotional state on false memory was studied from three aspects: false memory rate, EEG source localization and cortex functional network. The results show that the incidence of false memory in positive group is significantly higher than that in negative group. In positive emotion state, the frontal lobe of the brain is more active, the connection between the regions in the brain network is closer, and the information transmission speed is faster, which leads to more brain resources for semantic understanding and association of words, and then cause more false memory. However, the frontal lobe of the brain in the negative emotional state are not active, and the brain regions are less connected, which hinders the brain from understanding and associating words, only recalls some of the words they have seen in the learn stage. This paper studies how the emotional state of participants affects the incidence of false memory, which provides a theoretical basis for exploring the working mechanism of the brain. It may be useful for how to better avoid the occurrence of false memory, which has academic value and research significance.

6. Ethics approval and consent to participate

The experimental data in this study were obtained with the informed consent of all participants. The institutional review board of the Hebei University of Technology approved the experiment, code HEBUThMEC2020006.

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CRediT authorship contribution statement

Ying Li: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Zhaobing Ni:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Renjie He:** Writing – original draft. **Junyu Zhang:** Investigation, Data curation. **Zhimou Zhang:** Investigation, Data curation. **Shuo Yang:** Funding acquisition. **Ning Yin:** Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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