Effects of Depressive Tendency on Self-Focused and Situation-Focused Reappraisal: A Brain Network Study

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Abstract

Depression tendency represents a mild depressive state situated between depressive mood and major depressive disorder, and its continuous induction elevates the risk of developing depression. Cognitive reappraisal constitutes a widely utilized and effective emotion regulation strategy that can be categorized into self-focused reappraisal and situation-focused reappraisal; however, the alterations in regulation efficacy and brain network characteristics among individuals with depression tendency under these two strategies remain unclear. This study employed complex network analysis to investigate the regulation effects and brain network features in individuals with depression tendency during self-focused reappraisal and situation-focused reappraisal tasks. The results demonstrated that the depression tendency group exhibited lower valence ratings for both self-focused reappraisal and situation-focused reappraisal compared to the healthy control group, whereas arousal rating differences were not statistically significant; significant between-group differences were observed in clustering coefficient, local efficiency, and maximum betweenness centrality during both reappraisal tasks; divergent activation patterns in local brain regions were predominantly localized to the limbic lobe, frontal lobe, and parietal lobe. The abnormal brain network activity during self-focused reappraisal and situation-focused reappraisal tasks in the depression tendency group correlated with the severity of depression tendency. These findings suggest that aberrant brain network characteristics may signify impaired cognitive reappraisal function in individuals with depression tendency, offering novel insights for the prevention and amelioration of depression tendency symptoms.

Full Text

A Brain Network Study on the Influence of Depressive Tendency on Self-Focused Reappraisal and Situation-Focused Reappraisal

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Abstract

Depressive tendency represents a mild depressive state between normal depressed mood and clinical depression. When this state is continuously induced, it increases the incidence of major depressive disorder. Cognitive reappraisal is a widely used and effective emotion regulation strategy that can be divided into self-focused reappraisal and situation-focused reappraisal. However, it remains unclear how individuals with depressive tendency regulate emotions using these two strategies and how their brain network characteristics change in the process. This study employed complex network analysis to examine the regulatory effects and brain network features of individuals with depressive tendency during self-focused reappraisal and situation-focused reappraisal tasks. The results showed that both self-focused and situation-focused reappraisal valence ratings were lower in the depressive tendency group compared to the healthy control group, while arousal rating differences were not significant. Significant differences in clustering coefficients, local efficiency, and maximum betweenness centrality were observed between the two groups during both reappraisal tasks. Local brain area differences were primarily located in the limbic lobe, frontal lobe, and parietal lobe. Abnormal brain network activity during self-focused reappraisal and situation-focused reappraisal tasks in the depressive tendency group was associated with the severity of depressive tendency. These findings suggest that abnormal brain network characteristics may indicate impaired cognitive reappraisal function in individuals with depressive tendency, providing new insights for preventing and ameliorating depressive tendency symptoms.

Keywords: depressive tendency, cognitive reappraisal, self-focused reappraisal, situation-focused reappraisal, complex network

Introduction

Depressive tendency is a state between normal depressed mood and major depressive disorder that meets clinical diagnostic criteria (Rodríguez et al., 2012). Longitudinal studies have shown that individuals with depressive tendency have a five-fold increased risk of experiencing their first major depressive episode compared to control groups (Fogel et al., 2006). This indicates that depressive tendency places individuals at high risk for depression onset. If depressive tendency is continuously induced and cannot be alleviated, it is highly likely to develop into clinical depression. Furthermore, as an early stage of depression, depressive tendency, similar to major depression, can impact individuals' cognitive and social abilities to varying degrees (Tuithof et al., 2018). With increasing social competitiveness, manifestations of depressive tendency among young people are becoming more prevalent (彭婉晴 et al., 2019). Therefore, individuals with depressive tendency who have not yet met diagnostic criteria for major depression but exhibit decreased social functioning and carry a high risk of depression onset should receive significant attention.

Gross's (1998) process model of emotion regulation posits that emotion generation involves a temporal process beginning with psychologically relevant situations, including five stages: situation selection, situation modification, attentional deployment, cognitive reappraisal, and response modulation (Dryman & Heimberg, 2018). Cognitive reappraisal, as the most common, valuable, and adaptive emotion regulation strategy (Dillon & Pizzagalli, 2013), is defined as individuals reinterpreting the meaning of a situation or its relevance to the self to regulate emotions (Gross & Thompson, 2007; John & Gross, 2004). Ochsner et al. (2004) proposed that cognitive reappraisal comprises two subtypes: self-focused reappraisal and situation-focused reappraisal. Self-focused reappraisal involves increasing or decreasing subjective distance from the pictorial situation to regulate emotional experiences, while situation-focused reappraisal involves reinterpreting the meaning of situational content by focusing on the pictorial situation and attributing more positive or negative constructs to regulate emotional experience without directly changing the actual situation (Ochsner et al., 2004; Shiota & Levenson, 2009, 2012). Self-focused reappraisal includes two dimensions: detached reappraisal and engaged reappraisal; situation-focused reappraisal similarly includes two dimensions: positive reappraisal and negative reappraisal. To reduce negative emotions, existing research has predominantly utilized detached reappraisal from self-focused reappraisal and positive reappraisal from situation-focused reappraisal (Moser et al., 2014; Qi et al., 2017; Shiota & Levenson, 2002, 2009, 2012; Willroth & Hilimire, 2016).

Research has found that the ability to implement self-focused reappraisal (detached) to reduce negative emotions declines with age, while the ability to implement situation-focused reappraisal (positive) to reduce negative emotions gradually increases with age (Shiota & Levenson, 2009). Studies examining different age groups using both reappraisal strategies have found that while both strategies can effectively down-regulate negative emotions across age groups, differences exist in their regulatory effects (王彩凤 et al., 2021). Specifically, self-focused reappraisal in older adults relies on more cognitive processing resources and places higher demands on individuals' cognitive control abilities compared to situation-focused reappraisal (Liang et al., 2017).

Sun et al. (2020) investigated the regulatory effects of the two reappraisal subtypes and their impact on subsequent cognitive control, finding differences between the two subtypes in both negative emotion regulation effectiveness and subsequent cognitive control effects. fMRI studies have shown that the two reappraisal strategies share common neural mechanisms: both involve co-activation of the prefrontal cortex and amygdala systems (Ochsner & Gross, 2005; Ochsner et al., 2004). However, differences exist in their neural mechanisms. For instance, self-focused reappraisal activates the medial prefrontal cortex (PFC), which is associated with self-referential judgment and self-monitoring states (Gusnard et al., 2001; Kelley et al., 2002), and also activates the anterior cingulate cortex (ACC) (Kalisch et al., 2005). Self-focused reappraisal involves medial prefrontal regions, whereas situation-focused reappraisal involves lateral prefrontal regions (Ochsner et al., 2004). Additionally, the two sub-strategies differ in their effectiveness in improving negative emotions and in LPP amplitude changes. Situation-focused reappraisal not only reduces individuals' negative emotional experiences but also decreases LPP amplitude, whereas self-focused reappraisal only improves negative emotions without significant changes in LPP amplitude (Willroth & Hilimire, 2016).

Previous studies have shown that cognitive reappraisal can effectively regulate negative emotions in depressed populations (Ford et al., 2017; Lindsey et al., 2020), but findings lack consistency. Some studies have found that cognitive reappraisal benefits healthy and recovered depressed individuals in reducing negative emotions (Ehring et al., 2010). Additionally, depressed individuals show highly similar neural activation patterns to healthy individuals when using cognitive reappraisal strategies, suggesting that depressed individuals can use cognitive reappraisal to improve negative emotions (Belden et al., 2015). Aldao et al. (2010) found that the frequency of self-reported cognitive reappraisal use was negatively correlated with depressive symptoms. Lower frequency of cognitive reappraisal use predicted higher levels of depressive symptoms (Joormann & Gotlib, 2010). Liu et al. (2023) found that both reappraisal strategies could effectively up-regulate positive emotions and down-regulate negative emotions in individuals with depressive tendency, with positive cognitive reappraisal showing better effects. However, other studies have found that cognitive reappraisal is not always effective for depressed individuals (Diedrich et al., 2014; Joormann & Gotlib, 2010). For example, some studies have found that patients with major depressive disorder show poorer and less sustained cognitive reappraisal effects compared to healthy controls (Erk et al., 2010; 张阔 et al., 2016). Therefore, this study hypothesizes that inconsistent findings regarding the effectiveness of cognitive reappraisal in regulating depressed individuals may result from failing to examine its effectiveness from the perspective of reappraisal subtypes. Similarly, as an early stage of depression, the regulatory effects of cognitive reappraisal in depressive tendency may also be influenced by reappraisal subtypes. Based on this, this study hypothesizes that differences in regulatory effects exist between the depressive tendency group and healthy control group under different cognitive reappraisal conditions.

Most studies have found abnormal activity in local brain regions during cognitive reappraisal tasks in depressed individuals (Davis et al., 2018; Doré et al., 2018; Erk et al., 2010). However, the human brain is a complex network composed of different brain regions, and it is difficult to understand the functional integration and segregation in depressed individuals through local brain abnormalities alone (Zhang et al., 2011). Research has shown that important information about global and local brain functional networks can be obtained through complex network analysis (van den Heuvel & Hulshoff Pol, 2010), thereby understanding the degree of segregation and integration in brain networks (Wong et al., 2016). For example, some studies using complex network analysis have found disrupted topological neural mechanisms in individuals with major depressive disorder during resting state (Zhang et al., 2011), and that individuals with depressive tendency show impairments in both functional and structural networks at global and local levels (Zhang et al., 2022). During processing of negative emotions, they show significantly reduced activation in the superior frontal gyrus, middle frontal gyrus, and middle cingulate gyrus, and significantly increased functional connectivity between the superior frontal gyrus and caudate nucleus, striatum, and insula (Zhang, Kranz et al., 2020), with similar alteration patterns in the orbitofrontal cortex and left temporal gyrus to those observed in patients with major depressive disorder (Zhang, Zhao et al., 2020). Additionally, individuals with major depressive disorder show abnormal activity in default mode network regions during cognitive reappraisal tasks (Sheline et al., 2010), suggesting that individuals with depressive tendency may also exhibit abnormal neural changes during cognitive reappraisal. On one hand, because cognitive reappraisal includes self-focused and situation-focused subtypes, differences in regulatory effects between the two reappraisal tasks in individuals with depressive tendency may be related to changes in brain network characteristics. On the other hand, as a mild depressive state, whether the severity of depressive tendency is related to changes in brain network characteristics during tasks remains unknown. Therefore, it is essential to further investigate differences in global and local network features between the depressive tendency group and healthy control group under different cognitive reappraisal conditions, as well as the relationship between brain network characteristics and depressive tendency severity. Based on this, this study hypothesizes that compared with the healthy control group, the depressive tendency group will show abnormal activity in global and local network features under different cognitive reappraisal conditions, and that these features will be significantly correlated with depressive severity.

EEG can successfully measure the neural mechanisms of depressive symptoms at global or local network levels (Greco et al., 2021), and frequency domain analysis can quantify EEG signals into different frequency bands (Fingelkurts & Fingelkurts, 2015), with complex network analysis capable of obtaining relevant features of brain functional networks across different frequency bands (De Vico Fallani et al., 2007). Increasingly, studies based on EEG data have explored changes in brain network characteristics across different frequency bands in individuals with depression through complex network analysis (Mohammadi & Moradi, 2021; Shao et al., 2021). Research has shown that the alpha frequency band is closely related to depression (Aleksandra et al., 2023; Bruder et al., 2017; Liu, Chen et al., 2022; Sun et al., 2021) and is also associated with reduced emotional processing and emotional arousal (Balconi & Mazza, 2009). Gamma oscillations are crucial components of neural processes underlying higher cognitive functions, and previous studies have found they play important roles in emotional processing (Fitzgerald & Watson, 2018; Kang et al., 2014; Li et al., 2015). Therefore, this study will extract EEG signal features from alpha and gamma frequency bands through frequency domain analysis and combine complex network analysis to explore changes in brain network characteristics in individuals with depressive tendency during self-focused reappraisal and situation-focused reappraisal tasks.

In summary, this study will use complex network analysis combined with frequency domain analysis to investigate brain network characteristics in the depressive tendency group and healthy control group during self-focused reappraisal and situation-focused reappraisal tasks. Additionally, correlation analysis will be used to assess the relationship between depressive tendency severity and global and local network metrics, thereby exploring the extent to which brain network topological neural mechanisms reflect cognitive reappraisal behavior in individuals with depressive tendency.

Methodology

2.1 Participants

To obtain more accurate and valid results, this study administered multiple scales to participants to ensure the stability of screened individuals with depressive tendency. This study distributed and collected 1014 online questionnaires of the Beck Depression Inventory-II (BDI-II) through the Wenjuanxing platform to screen for individuals with depressive tendency who met initial screening criteria. The initial screening criteria were: BDI-II ≥ 14 for the depressive tendency preliminary group, and BDI-II ≤ 13 for the healthy control preliminary group (De Zorzi et al., 2021). Analysis of the preliminary screening questionnaire results identified 43 university students meeting initial criteria for the depressive tendency group, and 41 university students were randomly selected from the healthy control preliminary group. These individuals were then invited to the laboratory via telephone or WeChat for secondary screening. Upon arrival at the laboratory, participants were administered the Self-Rating Depression Scale (SDS) for secondary screening. The secondary screening criteria were: SDS $\geq$ 50 for the depressive tendency group, and SDS $<$ 50 for the healthy control group (Benning & Ait Oumeziane, 2017). Five participants from the depressive tendency group met initial screening criteria but not secondary criteria and were therefore excluded. The final sample consisted of 79 participants, including 38 in the depressive tendency group and 41 in the control group. All participants had no history of affective disorders or use of psychotropic medications, were right-handed, and had normal or corrected-to-normal vision.

2.2 Experimental Materials and Procedure

2.2.1 Experimental Materials A total of 160 scene pictures were selected from the International Affective Picture System (IAPS), including 120 negative pictures and 40 neutral pictures. Due to cultural differences in emotional evaluation of IAPS pictures among Chinese participants, an additional 21 participants (12 females; mean age = 22.00 years, SD = 2.57) were randomly selected to rate the valence and arousal of the pictures on a 1-9 scale before the formal experiment. Neutral picture valence (M = 5.22, SD = 0.68) and negative picture valence (M = 2.40, SD = 0.72) differed significantly, $t(158) = 21.62$, $p < 0.001$; neutral picture arousal (M = 4.16, SD = 0.80) and negative picture arousal (M = 7.27, SD = 0.87) also differed significantly, $t(158) = -19.96$, $p < 0.001$.

2.2.2 Experimental Task and Procedure The cognitive reappraisal task consisted of four blocks, with the first two blocks being passive viewing and the last two blocks being regulation conditions. These two conditions were counterbalanced across participants. Each block contained 40 pictures. To avoid fatigue, a 2-minute rest period was provided after each block. To help participants effectively switch between different task types, this study used color-coded backgrounds for instruction screens according to task type. The background colors for each task type were as follows: gray for viewing neutral, black for viewing negative, and green for reappraisal conditions (Jordan et al., 2022; Sullivan & Strauss, 2017; Thiruchselvam et al., 2011).

During the experiment, participants were simply required to view neutral and negative pictures carefully. In the self-focused reappraisal condition, the instruction word "detach" appeared on the screen, requiring participants to increase subjective distance while viewing the pictures, adopt a detached, third-person perspective on the events in the pictures, and minimize their negative emotions. For example, when seeing a picture of a patient, they should consider themselves as viewing the patient from an independent third-person perspective, with the person and situation being unrelated to themselves. In the situation-focused reappraisal condition, the instruction word "positive" appeared on the background, requiring participants to view the events in the pictures from an optimistic perspective and imagine that the people and events in the pictures were getting better. For example, when seeing a picture of a patient, they could imagine that the patient would soon recover.

Before the formal experiment, participants were required to carefully read the instructions and complete 12 practice trials. The formal experiment consisted of 40 trials per block. Each trial began with a fixation point for 500 ms, followed by an instruction word for 2000 ms, then a random blank screen for 300-700 ms, then an emotional picture for 3000 ms (Sullivan & Strauss, 2017), and finally participants rated the valence and arousal after emotion regulation on a 9-point scale according to the instructions (Thiruchselvam et al., 2011). The trial procedure is shown in Figure 1 [Figure 1: see original paper].

2.3 Data Collection and Analysis

The German Brain-Product company's ERPs recording and analysis system was used to collect EEG signals with a 64-channel electrode cap according to the international 10-20 system, with AFz as the ground electrode and FCz as the reference electrode. An electrode placed below the right eye recorded vertical electrooculogram (VEOG). The filter bandwidth was 0.01 Hz - 100 Hz, A/D sampling frequency was 500 Hz/channel, and impedance at each electrode was below 10 kΩ. EEG data were analyzed offline using Brain Vision Analyzer 2.0 software. Data were re-referenced using the reference electrode standardization technique (REST) with an infinite zero reference, with a sampling rate of 250 Hz. The filter passband was 0.01-30 Hz (Willroth & Hilimire, 2016). ICA was used to remove ocular artifacts. The analysis epoch was 2000 ms, with a baseline of 200 ms before stimulus onset. After segmentation and baseline correction, artifact-free data were imported into sLORETA software for source localization analysis.

2.4 Source Localization and Graph Theory Analysis

sLORETA was used for source localization of preprocessed data (Jaworska et al., 2012). sLORETA implements functional connectivity between 84 ROIs (42 left hemisphere Brodmann areas (BA) and 42 right hemisphere Brodmann areas). Connectivity analysis was performed by calculating phase lag index (PLI). Based on the MNI (Montreal Neurological Institute) coordinates of cortical voxels under the 64 electrode positions, 84 regions of interest (ROI) were defined as network nodes to obtain coordinate information for the 84 Brodmann areas, resulting in an 84$×$84 functional connectivity matrix. To investigate differences in global and local brain networks between the two groups during cognitive reappraisal tasks, this study used the GRETNA toolbox in MATLAB to convert connectivity matrices into binary networks with fixed sparsity. Currently, most studies integrate topological attribute measurements across the entire sparsity range, i.e., the AUC (Area under a curve) value, to avoid bias from selecting network sparsity. AUC represents the area under the curve of network measurements calculated across a range of thresholds (Borges et al., 2016). The threshold range selected in this study was 0.15-0.85 (Arnold et al., 2014).

Global network characteristic metrics mainly include clustering coefficient, characteristic path length, global efficiency, local efficiency, and maximum betweenness centrality. The clustering coefficient refers to the ratio of existing connections to possible maximum connections among a node's neighboring nodes, measuring the degree of clustering at the local level in the network (梁夏 et al., 2010). Local efficiency is the inverse of the shortest path length for a given node, measuring the efficiency of local information exchange (Latora & Marchiori, 2001). These two metrics primarily quantify functional segregation of the network, i.e., the ability to perform specialized processing in tightly connected brain regions. Characteristic path length, global efficiency, and maximum betweenness centrality mainly quantify functional integration of the network, i.e., the ability to rapidly combine specialized information from distributed brain regions. Characteristic path length is the average of the shortest path lengths between all pairs of nodes in the network, measuring parallel information transmission efficiency and functional integration degree (Rubinov & Sporns, 2010). Global efficiency is an average indicator of parallel information transmission between all node pairs in the network, measuring whether brain network transmission and information processing are efficient (Achard & Bullmore, 2007). Maximum betweenness centrality represents core hub nodes that are primarily responsible for communication and recovery of brain information (Hasanzadeh et al., 2020). In local network features, this study used betweenness centrality (BC) as a measure of the importance of individual nodes, which can better assess the influence of brain regions on information transmission in the network (Li et al., 2018).

2.5 Statistical Analysis

Statistical analysis was performed using SPSS Statistics 22.0. A 2 (group: depressive tendency group, healthy control group) × 4 (cognitive reappraisal condition: viewing neutral, viewing negative, situation-focused reappraisal, self-focused reappraisal) repeated measures ANOVA was used to investigate differences in subjective emotion ratings and global network features between the depressive tendency group and healthy control group under different cognitive reappraisal conditions, with group as a between-subjects variable and cognitive reappraisal condition as a within-subjects variable. Dependent variables included valence and arousal ratings and global network features. When sphericity test results violated the assumption of sphericity, Greenhouse-Geisser correction was used to adjust degrees of freedom, and the Bonferroni method was used to correct multiple comparison results for global network features. Independent samples t-tests were used to compare differences in local network features between the two groups under different frequency bands and cognitive reappraisal conditions, with False Discovery Rate (FDR) method used to correct multiple comparison results, where $p < 0.05$ indicated significant differences after correction. Pearson correlation coefficients were used to analyze the correlation between global and local network features and Beck Depression Inventory scores and Self-Rating Depression Scale scores in both groups, with Bonferroni method used to correct correlation results. Correlation analysis was completed using GRETNA.

Results

3.1 Participant Characteristics and Subjective Ratings

3.1.1 Participant Basic Information Demographic information and scale scores for the two groups are shown in Table 1 . The two groups showed no significant differences in age ($t(77) = 1.43$, $p = 0.156$) or gender ($^2(1) = 0.777$, $p = 0.378$). The depressive tendency group had significantly higher Beck Depression Inventory scores (20.34 ± 5.32) than the healthy control group (4.51

± 4.04), t(77) = -14.97, $p < 0.001$; the depressive tendency group also had significantly higher Self-Rating Depression Scale scores (60.13 ± 6.63) than the healthy control group (40.69 ± 7.46), t(77) = -12.21, $p < 0.001$. Additionally, analysis of Positive and Negative Affect Schedule scores revealed that the depressive tendency group had significantly lower positive affect (27.55 ± 4.86) than the healthy control group (34.34 ± 6.88), t(77) = 5.03, $p < 0.001$. Similarly, the depressive tendency group had significantly higher negative affect (25.63 ± 7.61) than the healthy control group (17.90 ± 6.97), t(77) = -4.71, $p < 0.001$.

3.1.2 Subjective Emotion Ratings Subjective emotion rating results for the depressive tendency group and healthy control group are shown in Table 2 . Analysis of valence ratings across different experimental task conditions revealed that sphericity test results violated the assumption of sphericity, $p < 0.001$, and Greenhouse-Geisser correction was applied. The main effect of cognitive reappraisal condition was significant, F(2.37, 182.18) = 114.03, $p < 0.001$, ^{2}p = 0.60. The main effect of group was significant, F(1, 71) = 6.08, p = 0.016, ^{2}p = 0.07, with overall lower valence ratings in the depressive tendency group compared to the healthy control group. The interaction between cognitive reappraisal condition and group was not significant (p = 0.669).

Analysis of arousal ratings across the four cognitive reappraisal conditions showed that sphericity test results violated the assumption of sphericity, $p < 0.001$, and Greenhouse-Geisser correction was applied. The main effect of cognitive reappraisal condition was significant, F(2.73, 210.27) = 48.63, $p < 0.001$, ^{2}p = 0.39. The main effect of group was not significant (p = 0.736), and the interaction between group and cognitive reappraisal condition was not significant (p = 0.963).

3.2 Brain Network Features

3.2.1 Global Network Features Global network feature results for the depressive tendency group during self-focused reappraisal and situation-focused reappraisal are shown in Table 3 , Table 4 , and Figure 2 [Figure 2: see original paper]. In the alpha frequency band, the main effect of group showed marginally significant differences in clustering coefficient (C), F(1, 71) = 3.04, p = 0.085, ^{2}p = 0.04; local efficiency (Eloc), F(1, 71) = 2.81, p = 0.098, ^{2}p = 0.04; and maximum betweenness centrality (maxBC), F(1, 71) = 3.11, p = 0.082, ^{2}p = 0.04. Other metrics showed no significant main effects of group ($p > 0.05$). In the gamma frequency band, the main effect of group showed significant differences in clustering coefficient (C), F(1, 71) = 8.29, p = 0.005, ^{2}p = 0.10; local efficiency (Eloc), F(1, 71) = 8.33, p = 0.005, ^{2}p = 0.10; and maximum betweenness centrality (maxBC), F(1, 71) = 7.16, p = 0.009, ^{2}p = 0.10. Other metrics showed no significant main effects of group ($p > 0.05$). The main effect of cognitive reappraisal condition showed marginally significant differences in clustering coefficient (C), F(1, 71) = 2.58, p = 0.055, ^{2}p = 0.03; significant differences in local efficiency (Eloc), F(1, 71) = 3.04, p = 0.030, ^{2}p = 0.04; and significant differences in maximum betweenness centrality (maxBC), $F(1, 71) = 3.33$, $p = 0.020$, $^2p = 0.04$. Other metrics showed no significant main effects of cognitive reappraisal condition ($p > 0.05$). Interactions between group and cognitive reappraisal condition were not significant for any metrics ($p > 0.05$).

3.2.2 Local Network Features Significant differences in betweenness centrality (BC) metrics between the depressive tendency group and healthy control group under different cognitive reappraisal conditions are shown in Table 5 , Table 6 , and Figure 3 [Figure 3: see original paper]. In the alpha frequency band, compared with the healthy control group, the depressive tendency group showed greater betweenness centrality in the left anterior cingulate cortex (ACC) (BA32, p = 0.001), right parahippocampal gyrus (PHG) (BA30, p = 0.010), and bilateral posterior cingulate cortex (PCC) (BA29, p = 0.029, p = 0.035), but lower betweenness centrality in bilateral superior/middle temporal gyrus (MTG/STG) (BA38, p = 0.014; BA39, p = 0.034), bilateral postcentral gyrus (PoCG) (BA2, p = 0.021; BA43, p = 0.046), and left inferior temporal gyrus (ITG) (BA20, p = 0.046).

In the gamma frequency band, compared with the healthy control group, the depressive tendency group showed increased betweenness centrality in bilateral parahippocampal gyrus (PHG) (BA35, p = 0.002, p = 0.004, p = 0.021; BA36, p = 0.023, p = 0.007, p = 0.030; BA28, p = 0.031, p = 0.018; BA27, p = 0.043, p = 0.029, p = 0.030, p = 0.037; BA30, p = 0.039), left anterior cingulate cortex (ACC) (BA24, p = 0.014), bilateral posterior cingulate cortex (PCC) (BA30, p = 0.017, p = 0.032; BA29, p = 0.021, p = 0.023, p = 0.024, p = 0.003, p = 0.009, p = 0.032; BA23, p = 0.003), bilateral superior temporal gyrus (STG) (BA22, p = 0.027; BA42, p = 0.031), left middle frontal gyrus (MFG) (BA8, p = 0.021), right precentral gyrus (PreCG) (BA4, p = 0.048, p = 0.035), and right postcentral gyrus (PoCG) (BA3, p = 0.033, p = 0.045), but decreased betweenness centrality in right middle temporal gyrus (MTG) (BA37, p = 0.012) and left inferior parietal lobule (IPL) (BA40, p = 0.018).

3.2.3 Correlation with Depressive Tendency Severity Correlation analysis between global network features and depressive tendency severity in the depressive tendency group was conducted by analyzing metrics showing differences in global network features across different frequency bands, namely clustering coefficient (C), local efficiency (Eloc), and maximum betweenness centrality (maxBC), with Beck Depression Inventory scores (BDI) and Self-Rating Depression Scale scores (SDS). Pearson correlation analysis was performed with Bonferroni correction, and results are shown in Figure 4 [Figure 4: see original paper]. In the alpha frequency band, under the viewing negative condition, SDS scores in the depressive tendency group showed significant negative correlation with clustering coefficient (C) (r = -0.375, p = 0.020) and local efficiency (Eloc) (r = -0.375, p = 0.020), and significant positive correlation with maximum betweenness centrality (maxBC) (r = 0.376, p = 0.020). In the gamma frequency band, under the self-focused reappraisal condition, SDS scores in the depressive tendency group showed significant negative correlation with clustering coefficient (C) (r = -0.320, p = 0.050) and local efficiency (Eloc) (r = -0.363, p = 0.025).

Correlation analysis between local network features and BDI and SDS scores in the depressive tendency group was performed with Bonferroni correction, as shown in Figure 5 [Figure 5: see original paper]. In the alpha frequency band, under the viewing negative condition, SDS scores in the depressive tendency group showed significant positive correlation with left middle/superior temporal gyrus (MTG/STG) (BA38, p = 0.014) and left postcentral gyrus (PreCG) (BA43, p = 0.029). In the gamma frequency band, under the viewing negative condition, BDI scores in the depressive tendency group showed significant positive correlation with right middle temporal gyrus (MTG) (BA37, p = 0.019).

Discussion

This study used complex network analysis to investigate the regulatory effects and brain network characteristics of self-focused reappraisal and situation-focused reappraisal in individuals with depressive tendency, and the relationship between these characteristics and depressive tendency severity. The results showed: (1) The depressive tendency group had lower valence ratings for both self-focused reappraisal and situation-focused reappraisal, indicating less effective regulation; (2) Significant differences in clustering coefficient, local efficiency, and maximum betweenness centrality were observed between the two groups during self-focused reappraisal and situation-focused reappraisal tasks; local brain area differences were primarily located in the anterior and posterior cingulate cortex, parahippocampal gyrus, precentral gyrus, postcentral gyrus, middle frontal gyrus, superior frontal gyrus, superior temporal gyrus, and middle temporal gyrus; (3) Global network features in the depressive tendency group during self-focused reappraisal tasks were correlated with depressive tendency severity, and both global and local network features during viewing negative tasks were correlated with depressive tendency severity. These findings suggest that changes in functional segregation and integration of global networks and importance of local brain areas may affect cognitive reappraisal effectiveness in individuals with depressive tendency.

4.1 Effectiveness of Self-Focused and Situation-Focused Reappraisal in Depressive Tendency

This study examined differences in valence and arousal between the depressive tendency group and healthy control group during self-focused reappraisal and situation-focused reappraisal. The results showed that the depressive tendency group had significantly lower valence ratings than the healthy control group, indicating that individuals with depressive tendency experienced more negative emotions during self-focused reappraisal and situation-focused reappraisal processes, and that the depressive tendency group was less effective at reducing negative emotions using cognitive reappraisal sub-strategies than the healthy control group. This suggests that depressive symptoms may affect individuals' emotion regulation processes (Liu, Ma et al., 2022). Previous research has found that early adverse life experiences contribute to the formation of negative cognitive schemas in depressed individuals, characterized by automatic processing that does not consume cognitive resources (Beck, 2008). When these schemas are repeatedly activated before or during depressive episodes, individuals automatically adopt negative emotion regulation strategies when facing similar negative stimuli (Ehring et al., 2010). Since both reappraisal sub-strategies require individuals to consciously reinterpret negative emotional stimuli and mobilize cognitive resources to regulate emotions (Gyurak et al., 2011), and depressed individuals have limited cognitive resources during cognitive reappraisal tasks (Joormann & Gotlib, 2010), the depressive tendency group cannot use both sub-strategies as effectively as the healthy control group to regulate negative emotions, which may further lead to the development and maintenance of depression. However, overall, both sub-strategies can reduce negative emotions to some extent in individuals with depressive tendency, with no significant difference in effectiveness between them. Since individuals with depressive tendency have weaker approach motivation for happy stimuli and weaker avoidance motivation for sad stimuli than normal individuals, both distancing from negative emotions and focusing on positive aspects of negative events have similar effects. Additionally, this study found no significant differences in arousal ratings between the depressive tendency group and healthy control group during both reappraisal tasks. The possible reason may be that individuals with depressive tendency have reduced ability for fine processing of negative stimuli (李红 et al., 2019), leading to low motivational responses to high-intensity negative stimuli. Future research could categorize negative emotional pictures into different types and intensities to conduct in-depth studies on emotional arousal in individuals with depressive tendency.

4.2 Global Network Features of Self-Focused and Situation-Focused Reappraisal in Depressive Tendency

This study investigated global network features in the depressive tendency group and healthy control group during self-focused reappraisal and situation-focused reappraisal. The results showed abnormal activity in alpha and gamma frequency bands in the global brain network features of the depressive tendency group during both reappraisal tasks. These results are consistent with previous research. For example, studies exploring individuals with major depressive disorder and cognitive impairment during cognitive reappraisal of negative stimuli have found abnormal activity in the alpha frequency band (Liu, Ma et al., 2022), suggesting that impaired cognitive reappraisal in depressed individuals may be related to abnormal activity in low-frequency bands. Additionally, research exploring brain functional networks in patients with major depressive disorder during emotional stimulus processing has found abnormal activity in the gamma frequency band (Li et al., 2015). Therefore, the effectiveness of cognitive reappraisal in individuals with depressive tendency may be affected by abnormal activity in alpha and gamma frequency bands in the global brain network.

The clustering coefficient quantifies the degree of connectivity among adjacent regions, thus measuring the brain network's ability to process local information (梁夏 et al., 2010). The results showed that the clustering coefficient in the depressive tendency group during self-focused reappraisal and situation-focused reappraisal tasks was significantly decreased compared to the healthy control group, consistent with previous research. Studies have found that individuals with major depressive disorder show significantly decreased clustering coefficients during cognitive reappraisal tasks, representing reduced ability for local information processing in the brain and consequently affecting emotion regulation effectiveness (Liu, Chen et al., 2022). Local efficiency measures the efficiency of information transmission in brain networks (Latora & Marchiori, 2001), and the depressive tendency group showed significantly lower local efficiency than the healthy control group during both reappraisal tasks, indicating that individuals with depressive tendency have impaired efficiency in processing negative emotional stimuli and that cognitive reappraisal ability may be affected by depressive mood (Liu, Chen et al., 2022). Maximum betweenness centrality represents nodes with high centrality (Hasanzadeh et al., 2020), reflecting information transmission between brain regions in the network (Bullmore & Sporns, 2009). The results showed that maximum betweenness centrality in the depressive tendency group during self-focused reappraisal and situation-focused reappraisal tasks was significantly lower than in the healthy control group. This suggests that both brain network integration efficiency and cognitive reappraisal effectiveness are lower in individuals with depressive tendency.

4.3 Local Network Features of Self-Focused and Situation-Focused Reappraisal in Depressive Tendency

Related research suggests that local brain features represent the ability for cross-regional information transmission in brain networks (Wong et al., 2016), reflecting the neurobiological basis of information transmission and integration (Olaf et al., 2007). This study evaluated changes in local features of cortical networks by calculating node betweenness centrality (BC).

Analysis of betweenness centrality (BC) in the gamma frequency band revealed abnormal activity in the posterior cingulate cortex, parahippocampal gyrus, precentral gyrus, postcentral gyrus, and middle frontal gyrus in the depressive tendency group during self-focused reappraisal and situation-focused reappraisal tasks. The two cognitive reappraisal subtypes have different neural mechanisms, with self-focused reappraisal involving abnormal activity in more brain regions compared to situation-focused reappraisal tasks.

Compared to the alpha frequency band, individuals with depressive tendency showed abnormal activity in more brain regions in the gamma frequency band. Since gamma oscillations play important roles in emotional processing (Fitzgerald & Watson, 2018), this frequency band helps identify changes in individuals' emotional states (Murugappan et al., 2021). In the gamma frequency band, during self-focused reappraisal tasks, individuals with depressive tendency showed abnormal activity not only in bilateral posterior cingulate cortex, left parahippocampal gyrus, left middle frontal gyrus, and right precentral gyrus, but also in right parahippocampal gyrus and right postcentral gyrus. Specifically, the posterior cingulate cortex primarily receives input from parietal cortex and participates in spatial memory systems (Rolls, 2019). Due to the influence of previous negative emotional events (Beck, 2008), individuals with depressive tendency may activate certain negative memories during both reappraisal tasks, thereby affecting cognitive reappraisal effectiveness. Parahippocampal gyrus impairment may affect the ability of individuals with depressive tendency to reinterpret negative contexts based on contextual cues during self-focused reappraisal and situation-focused reappraisal (Frank et al., 2014). Self-focused reappraisal tasks are simultaneously affected by bilateral parahippocampal gyrus, a process that relies more heavily on individuals' ability to reinterpret negative contexts. Once this ability is impaired, the regulatory effect of self-focused reappraisal on negative emotions will be reduced. The postcentral gyrus is related to emotional perception and processing (Kassam et al., 2013), and impairment in this region may lead to abnormal emotional responses, particularly affecting the effectiveness of self-focused reappraisal in individuals with depressive tendency. The precentral gyrus is associated with negative cognitive styles (Picó-Pérez et al., 2017). The cognitive model of depression proposes that early adverse events promote the formation of negative cognitive schemas, which when activated by negative emotional events, lead to negative biases in memory and emotion (Beck, 2008). Furthermore, the middle frontal gyrus is responsible for regulating emotional processing (Zhang et al., 2020) and is related to flexible regulation of attention (Song et al., 2019). Its abnormal activity may play a role in attentional orientation toward negative stimuli, making individuals prone to reactivating negative schemas when faced with sufficient negative stimuli (Davidson et al., 2002). Therefore, impairment in these two regions may represent the neural basis of negative cognitive bias in depressed individuals. If the middle frontal gyrus shows processing abnormalities, it will greatly affect the ability of individuals with depressive tendency to use situation-focused reappraisal strategies, but have less impact on self-focused reappraisal effectiveness.

Additionally, the results showed that compared with the healthy control group, the depressive tendency group exhibited abnormal activity in the right superior temporal gyrus, right middle temporal gyrus, posterior cingulate cortex, bilateral inferior frontal gyrus, right postcentral gyrus, and right superior parietal lobule during cognitive reappraisal tasks in the alpha frequency band. Abnormal activation in the superior temporal gyrus is consistent with previous research (Ramezani et al., 2014). The superior temporal gyrus (STG) belongs to the temporal lobe, which reflects attention to emotion-related features that are crucial for triggering and reinterpreting emotions (Bebko et al., 2011). Individuals in cognitive reappraisal tasks need not only to identify emotional stimulus information but also cognitive effort to down-regulate negative emotions; therefore, abnormal activity in the superior temporal gyrus may reflect decreased cognitive control ability in individuals with depressive tendency. The parietal lobe is primarily responsible for individuals' cognitive control abilities (Anderson & Huddleston, 2012), and abnormal activity in this region indicates that individuals with depressive tendency cannot inhibit negative emotions when viewing negative pictures, which affects the regulatory effectiveness of situation-focused reappraisal. The inferior frontal gyrus is primarily responsible for down-regulating negative emotional responses (Kravitz et al., 2011) and plays an important role in response inhibition (Aron et al., 2004; Hampshire et al., 2010). Previous research has also found inhibitory control deficits in patients with major depressive disorder (Langenecker et al., 2007), suggesting that individuals with depressive tendency may be affected by the inferior frontal gyrus, making it difficult to inhibit negative emotions and thereby affecting task performance under situation-focused reappraisal, but not affecting the regulatory effectiveness of self-focused reappraisal (Dai & Feng, 2011). In summary, changes in betweenness centrality in brain regions including the posterior cingulate cortex, parahippocampal gyrus, precentral gyrus, postcentral gyrus, middle frontal gyrus, superior frontal gyrus, parietal lobe, superior temporal gyrus, and middle temporal gyrus in individuals with depressive tendency indicate that these brain regions are significantly affected (Long et al., 2015) and show differences during self-focused reappraisal and situation-focused reappraisal tasks.

4.4 Correlation Between Brain Networks and Depressive Tendency Severity

Correlation between brain networks and depressive tendency severity in individuals with depressive tendency further confirms that depression affects brain topological neural mechanisms. Specifically, this study found that the severity of depressive tendency was negatively correlated with clustering coefficient and local efficiency. Since clustering coefficient and local efficiency primarily reflect information transmission between brain regions in networks (Rubinov & Sporns, 2010), this suggests that higher severity of depressive tendency may be associated with slower brain information transmission efficiency (Meng et al., 2014). Local network features were also correlated with depressive tendency severity. The severity of depressive tendency was positively correlated with middle temporal gyrus/superior temporal gyrus and left postcentral gyrus. Therefore, this study hypothesizes that symptom development in individuals with depressive tendency may be related to neural activity in these brain regions, providing insight into the extent to which brain network properties reflect cognitive reappraisal behavior and depressive severity in individuals with depressive tendency.

4.5 Limitations and Future Directions

In summary, this study helps reveal the effectiveness of cognitive reappraisal strategies used by individuals with depressive tendency and corresponding changes in brain neural mechanisms, supplementing research on depressive tendency. However, several limitations remain: (1) This study only investigated brain networks during cognitive reappraisal tasks in individuals with depressive tendency using EEG data. Future research could employ multimodal EEG/fMRI integration methods (Lioi et al., 2020; Zhang et al., 2011) to explore richer results. (2) This study only measured static brain networks while ignoring dynamic brain networks. Future research should explore dynamic analysis and temporal network characteristics of brain networks (Liu et al., 2019). (3) This study primarily investigated the conscious level of cognitive reappraisal. Future research could consider the unconscious level of cognitive reappraisal to enrich relevant studies.

Conclusion

This study used complex network analysis to investigate the effectiveness and brain network characteristics of self-focused reappraisal and situation-focused reappraisal in individuals with depressive tendency, and the relationship between these characteristics and depressive tendency severity. The results showed that both global and local network features were altered in individuals with depressive tendency, which was also related to depressive tendency severity. This suggests that abnormal topological neural mechanisms may indicate impaired cognitive reappraisal function in individuals with depressive tendency and provide new insights for preventing and ameliorating depressive tendency symptoms.

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Note: Figure translations are in progress. See original paper for figures.