Fundamental Research 5 (2025) 115–123

Contents lists available at ScienceDirect

Fundamental Research

journal homepage: http://www.keaipublishing.com/en/journals/fundamental-research/

Article

Cognitive reappraisal improves the social decision-making performance of suicide attempters

Tong Wang[a,1], Xiaoya Liu[a,1], Moxin Duan[a], Bo Zhang[a], Li An[b,*], Shuang Liu[a,*], Dong Ming[a,c]

[a] *Academy of Medical Engineering and Translational Medicine, Tianjin University, Tianjin 300072, China*
[b] *School of Education, Tianjin University, Tianjin 300072, China*
[c] *School of Precision Instruments and Optoelectronics Engineering, Tianjin University, Tianjin 300072, China*

A R T I C L E I N F O

Article history:
Received 31 August 2023
Received in revised form 8 May 2024
Accepted 20 June 2024
Available online 2 July 2024

Keywords:
Suicide attempters
Decision-making
Ultimatum game
Cognitive reappraisal
Late-positive potential
Theta-gamma coupling

A B S T R A C T

A growing body of evidence suggests that emotion regulation (ER) plays a crucial role in the decision-making (DM) process of suicide attempters (SA). Cognitive reappraisal (CR), an emotion regulation strategy that reinterprets emotional situations to alter physiological and emotional responses, has been studied widely. Whereas, its effect on SA is yet to be explored. The present study attempted to use CR to modulate ER in SA to improve their DM performance, and explore the physiological mechanisms underlying this process. Scale scores under natural responses and after using the CR strategy, as well as behavioral and electroencephalographic (EEG) data from subjects were recorded during the classical DM task - ultimatum game (UG) paradigm. 52 patients with psychiatric disorders (including 26 SA and 26 non-suicide attempters) and 22 healthy controls (HC) performed in UG. Scale results showed that negative emotional experience scores decreased in all three groups after CR, but SA showed less improvement compared to HC. The behavioral results showed that acceptance of SA significantly increased after CR in both fair and unfair alternatives in the UG task, suggesting that CR can improve DM performance of SA. Besides, we extracted the late-positive potential (LPP) and theta-gamma coupling (TGC) of EEG for analysis. The LPP of SA was significantly higher when facing unfair alternatives than in fair ones, reflecting the fact that SA showed stronger negative emotions in the face of unfair situations. In addition, SA exhibited TGC diminished in frontotemporal regions when facing unfair allocation schemes, which demonstrated the existence of cognitive impairment in SA. This study verified the feasibility of CR for the moderation of DM ability in SA and provided new ideas for early intervention of suicidal behavior.

1. Introduction

Suicide is one of the leading causes of death worldwide. According to the latest report by the World Health Organization (WHO), over 700,000 people die by suicide each year [1]. Suicide imposes a significant burden on individuals, families, and societies, making it a serious global public health issue [2]. Therefore, suicide prevention should be prioritized in national healthcare agendas.

Suicide attempt is considered a consistently identified risk factor for both non-fatal and fatal suicidal behavior [3,4]. It typically refers to non-lethal acts with an intent to die but with the potential for causing serious self-harm [5]. In recent years, it has garnered significant attention from scholars. Suicide attempts often recur with each subsequent attempt, indicating a higher lethality potential [6]. Nearly half of severe suicide attempters (SA) make another suicide attempt within five years, and the risk of completed suicide is several tens to hundreds of times higher than that of the general population [4,6]. Therefore, a comprehensive understanding of SA is crucial at both clinical and neurobiological levels to prevent future suicidal behavior. The "neurocognitive model of suicidal behavior" proposed by Jollant et al. highlights that altered value attribution modulation is one of the cognitive impairments commonly observed in SA, closely associated with disadvantageous decision-making (DM) in a social context [7]. Impaired DM resulting from emotional dysfunction is considered a neurocognitive risk factor for suicidal behavior [8].

A large number of studies have now confirmed the impairment of DM functions in SA [7,9]. DM, part of executive functioning, is the process of choosing between competing alternatives, in which individuals weigh the costs and benefits of each possible decision and estimate the consequences of their behavior [9]. Research has shown that during the DM process, SA tend to disregard outcome probabilities [10]. They have a tendency to choose risky and disadvantageous options [8], as well as struggle to integrate knowledge from past experiences into

* Corresponding authors.
E-mail addresses: anli_mhc@tju.edu.cn (L. An), shuangliu@tju.edu.cn (S. Liu).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.fmre.2024.06.008

their ongoing DM [11]. DM deficits increase the potential for suicidal behavior in people [12]. A study comparing the performance of patients with bipolar disorder with and without a history of suicide attempts in the Iowa Gambling Task (IGT) found that patients with a history of suicide attempts had poorer DM performance [13]. Similar results have also been found in non-clinical samples, further confirming the robust association between decision impairments as a susceptibility factor closely linked to suicidal behavior, independent of specific psychiatric disorders [14]. However, much of the research has focused on investigating changes in risk DM among SA, with less emphasis on the regulation of DM performance among SA in a social context.

Social DM refers to the process of judgment and choice that individuals engage in within a context of social interaction. It encompasses various phenomena such as social reciprocity, altruistic behavior, interpersonal trust, and a sense of fairness [15]. Social DM is a form of fuzzy DM that is typically influenced by both the social DM environment and the interaction between individuals. When making decisions in a social context, individuals need to accurately detect and utilize contextual cues. However, individuals with a history of suicide attempts exhibit decision impairments when performing decision tasks in a social background. They show insensitivity to rewards and punishments and are unable to employ decision strategies that are advantageous based on social cues, thus demonstrating decision deficits [16].

One of the commonly used paradigms to study DM in a social interaction context is the ultimatum game (UG) paradigm [17]. In the UG, a proposer suggests a way to divide a fixed amount of money, and the responder must either accept or reject the proposal. If the responder accepts the proposal, the suggested allocation is implemented. If the responder rejects the proposal, neither party receives anything. In the UG, the responder's (individual-level) strategy for maximizing rewards is to accept all proposals, while the proposer's strategy for maximizing rewards is to make the smallest possible proposal [17]. However, in the UG, people do not always pursue their own maximum benefit [18]. Szanto et al. [18] used the UG paradigm to observe the impact of perceived social injustice on DM in social interactions. They observed that older depressed individuals with a history of high-lethality suicide attempts predominantly rejected unfair proposals based on a sense of unfairness, disregarding their own economic losses. Decisions in a social context are influenced by emotion regulation (ER) strategies [16], thus improving the ER abilities of SA is of great significance in addressing social DM impairments and reducing suicide risk.

ER, the process of regulating various components of emotional activity [19], plays a crucial role in maintaining mental health and preventing suicide or self-harm [20,21]. Cognitive reappraisal (CR), as an ER strategy, aims to encourage individuals to reevaluate emotional events and reinterpret them from a positive perspective, thereby reducing negative emotions [21]. Research has shown that adopting CR as an ER strategy effectively reduces emotional experiences, expressions, and physiological reactions in individuals [22], leading to a reduction in negative emotions at both behavioral and neural levels [20] and decreasing the influence of emotions on DM behavior [23]. Currently, studies on ER among SA mainly focus on the use of ER strategies. However, further investigation is needed to understand the direct impact of ER strategies on the social DM of SA.

Existing suicide risk measurements heavily rely on subjective assessments, and there is an urgent need for more objective and comprehensive indicators of suicide risk to fully reflect the complex pathological mechanisms involved. Electroencephalogram (EEG) features demonstrate significant potential for generating neurophysiological pattern information of suicide patients in a cost- and time-efficient manner, offering possibilities for improving the current suicide risk assessment and prevention [3]. Since the DM process unfolds over time, event-related potential (ERP) techniques in EEG analysis can be used to assess emotional changes in SA [24]. When the EEG is time-locked to the presentation of specific events and stimuli, the voltage modulation that occurs over time is referred to as ERPs [25]. ERP, as an important method for studying DM, with their high temporal resolution, helps reveal underlying psychological activities and cognitive processes during DM. In recent years, ERP studies focused on CR strategies have mainly centered around the influence of the Late Positive Potential (LPP). The LPP is a centroparietal maximum positive ERP component that typically appears around 400 milliseconds after stimulus onset. It is commonly associated with attention and evaluative processes related to task-relevant stimulus [26,27]. The LPP is modulated by bottom-up image content and is larger in response to emotional stimuli compared to neutral stimuli, making it a potential surrogate measure of ER [28,29]. Research has shown that following CR, the LPP elicited by negative stimuli is significantly reduced [29,30]. Studies have shown a significant reduction in LPP following CR, particularly in response to negative stimuli [29,30]. However, the performance of LPP in SA undergoing CR as an ER strategy in clinical settings is not yet clear. Exploring the LPP response of SA under CR can contribute to further understanding the role of ER in suicide risk.

In addition to ERPs, phase-amplitude coupling (PAC) is a promising method for studying cognitive processes. PAC is a form of cross-frequency coupling (CFC) between different frequency neural oscillations, where high-frequency amplitude is modulated by low-frequency phase [31]. PAC has been found to be potentially correlated with changes in brain function, and several studies have reported abnormal PAC in patients with psychiatric disorders [32]. Chattun et al. conducted a magnetoencephalography (MEG) study on patients with major depressive disorder (MDD) during resting-state and found a significant reduction in alpha-gamma PAC between the right caudate and left thalamus in the high-suicide-risk group compared to the low-suicide-risk group and healthy controls [33]. Our previous study [34] also indicated a significant reduction in theta-gamma coupling (TGC) in the natural responses (NR) of SA during a DM task. Therefore, exploring changes in PAC under NR conditions and after CR conditions in psychiatric patients can provide insights into their neurocognitive processes.

This study aims to investigate the ER effects of CR strategies on SA in a clinical setting. We combined behavioral and EEG assessments to examine the regulatory effects of CR on fair DM performance in SA during an UG task. By comparing inter-group and intra-group changes in behavioral and electrophysiological data, we aim to explore the differential characteristics of DM under NR conditions and after the use of CR as an ER strategy in SA, non-suicide attempters (NSA), and healthy controls (HC). This will provide an objective evaluation of the impact of CR strategies on fair DM performance in SA.

2. Methods and experiments

2.1. Participants

A total of 74 participants were recruited for this study, with ages ranging from 18 to 60 years old and an average age of 38 years. All participants were right-handed. Among them, a total of 52 clinical psychiatric disorder patients were recruited from Tianjin Anding Hospital. All patients were diagnosed by the same experienced clinical psychiatrist based on the International Statistical Classification of Diseases 10th Revision (ICD-10). The Suicide Definition and Classification System (SD-VCS) was used in this study to define and classify suicide. Based on their history of suicide attempts, patients were divided into a SA group consisting of 26 participants (male: 12; female: 14) and a NSA group consisting of 26 participants (male: 8; female: 18). There were no significant differences in gender ratio and age between the two groups. Additionally, 22 age- and gender-matched healthy individuals (male: 6; female: 16) were recruited as a HC group from nearby communities, streets, and schools.

The inclusion criteria for the SA group were as follows: (1) individuals with a documented history of suicide attempts based on interviews with clinical doctors and electronic medical records; (2) no history of diagnosed organic brain disorders or chronic physical illnesses; (3)

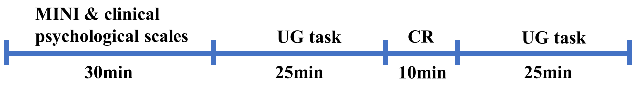

Fig. 1. Experimental flow chart.

considering that suicide behavior is often associated with a history of depression, bipolar affective disorder, and schizophrenia, clinically diagnosed patients with depression, bipolar disorder, or schizophrenia were allowed to participate, while patients in manic or mixed episodes were excluded; (4) ability to understand the task instructions and cooperate in the collection of EEG data.

The inclusion criteria for the HC group were as follows: (1) no history of suicidal behavior or any mental health issues, both physically and mentally healthy; (2) no prior diagnosis of any psychiatric disorders or other physical illnesses; (3) exclusion of participants studying in applied psychology, psychiatry, or engaging in professions related to psychology. Participants should not have any language comprehension disorders, color blindness, and should have normal or corrected vision.

This study incorporated the ICD-10, Mini International Neuropsychiatric Interview (MINI), Beck Scale for Suicidal Ideation (BSI), Beck Depression Inventory (BDI), State-Trait Anxiety Inventory (STAI), and Positive and Negative Affect Schedule (PANAS) to assess the patients.

The project was approved by the Ethics Committee of Tianjin University and Ethics Committee of Tianjin Anding Hospital. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study. All participants provided informed consent and received appropriate gifts based on their performance at the end of the program.

2.2. Experimental design

2.2.1. Procedures

The experiment consists of three sequential task stages: a 25-minute UG task under NR conditions, a 10-minute CR strategy training, and a 25-minute UG task under CR conditions (as shown in Fig. 1).

Before the experiment begins, a professional staff conducts a brief MINI with the participants for approximately 30 minutes and completes clinical psychological scales according to the guidelines. Once the preparations are complete, the participants sit in front of the computer screen, and the experimenters explain the tasks, ensuring that the participants fully understand and become familiar with the task content before starting the experiment.

In the UG task, the participants visually attend to the screen and respond by pressing either the accept key (‘F’) or the reject key (‘J’) for the allocation schemes presented. The participants first practice with five trials and then proceed to the formal experiment, which consists of a total of 100 trials. After all the trials are completed, the total amount obtained by the participants is displayed on the screen. Following the experiment, the participants are required to complete the PANAS and rate each allocation scheme on a scale of 1 to 7, indicating fairness (1 = very unfair, 7 = very fair).

Next, the participants undergo CR strategy training. The training process follows the method proposed by Grecucci et al. [35,36], which will be further explained in Section 2.2.3. During the training, the participants practice using the CR strategy several times, and their success in employing the strategy in the task is rated on a scale of 1 to 7. The overall judgment of successful use of the CR is based on the rating results, combined with the participants’ subjective responses. A rating of 4 or above is generally considered as correctly using the strategy, while a lower rating prompts continued CR training.

Once the participants are able to successfully employ the strategy, the UG task is conducted again, consisting of a total of 100 trials. This task is identical to the UG task under NR conditions. After the experiment, the participants complete the PANAS once more and rate each allocation scheme on a scale of 1 to 7, indicating fairness level.

2.2.2. Ultimatum game (UG)

The UG is a classic paradigm used to study social DM. In this study, an adapted Chinese version of the classic UG task was utilized (Fig. 2 a [37]). Two participants were each given a fixed amount of money (100 RMB). One player acts as the proposer and the other as the responder. The proposer needs to propose a distribution plan to the responder, and there are five distribution plans to choose from (90/10, 80/20, 70/30, 60/40 and 50/50). After the allocation scheme is proposed, the responder has the right to decide whether to accept it or not. If accepted, the transaction is successful and both parties receive their respective amounts. If rejected, the deal is unsuccessful and neither party benefits. The 90/10 and 80/20 schemes are considered unfair, while the 60/40 and 50/50 schemes are considered fair. The 30/70 scheme is considered a neutral allocation.

In this study, the participants act as responders in the DM task and are informed that the allocation schemes they receive were proposed by other participants, although in reality, these schemes are predetermined by a computer and presented randomly. The entire experiment lasts approximately 90 minutes. At the end of the experiment, the participants receive a gift of equivalent value to the amount earned during the experiment.

2.2.3. Cognitive reappraisal (CR)

The specific procedure for CR training is as follows: The experimenter introduces the definition of CR strategy to the participants and provides multiple explanations using negative images (e.g., Fig. 2b). (1) We may think that this woman is going through the pain of losing a child and feels very sad and difficult to accept. (2) We may also think that this woman is just tired and experiencing a minor headache. Both interpretations are reasonable, but the latter (2) appears less negative compared to (1), resulting in a reduction of negative experiences. We refer to this method as CR. The participants are required to explain a series of negative images and adopt less negative interpretations as much as possible. After successfully using this strategy, the participants are instructed to employ CR in the subsequent UG task. They are prompted to imagine that the proposer in the task might be facing financial difficulties or have a great need for the money when encountering unfair allocation schemes, thereby reducing negative experiences. The negative images used during the training phase are selected from the Chinese Affective Picture System database.

2.3. Data acquisition

The present study utilized the SynAmps2, a brainwave signal recorder manufactured by Neuroscan, USA. The Neuroscan 4.5 system was used to collect EEG signals, and electrodes were placed according to the international standard 10/20 electrode placement system. The EEG signals were recorded at a sampling frequency of 1,000 Hz, and a notch filter at 50 Hz was applied to remove power line interference. The bandpass filter ranged from 0.01 to 70 Hz. In this study, the left mastoid (‘M1’) electrode was chosen as the reference electrode, and a total of 60 electrode channels were recorded. Throughout the entire experiment, the impedance of each channel was maintained below 5 kΩ.

2.4. Data analysis

2.4.1. Preprocessing

The preprocessing of the electroencephalogram (EEG) data was performed using the EEGLAB toolbox in MATLAB (version 2016a). The preprocessing of the EEG data involved referencing the raw data to the average of the bilateral mastoids ([M1 + M2]/2), bandpass filtering the data within the range of 0.1–150 Hz, down-sampling to 500 Hz, and using Independent Component Analysis (ICA) to remove signal artifacts.

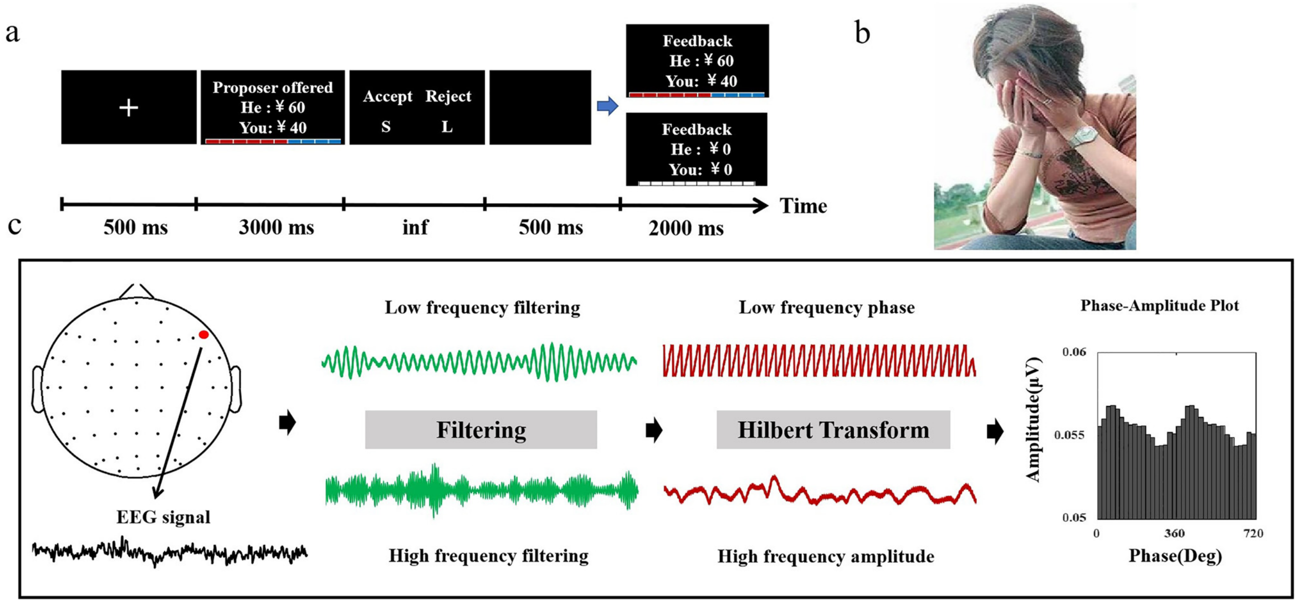

Fig. 2. (a) Illustration of the UG. (b) CR Strategies Training Materials: "The Crying Woman". (c) Schematic diagram of the steps for calculating the MI) for PAC.

The data were segmented from 200 ms before stimulus onset to 800 ms after stimulus onset, according to the stimulus presentation paradigm. A baseline correction was applied to the data from 200 ms before stimulus onset. Epochs with peak-to-peak amplitudes exceeding ± 100 μV were excluded as outliers. Finally, an average of approximately 30 trials per condition (fair, unfair) was obtained.

2.4.2. ERP analyses

We selected the representative event-related potential (ERP) component, the Late Positive Potential (LPP), which reflects individual DM processes, for analysis. The LPP is a late positive component of the brain's electrical activity occurring 400 ms after stimulus presentation. This component is mainly distributed in the parietal region and reflects subjective perception and evaluation of emotionally relevant stimuli. Combining the previous related studies and the waveform characteristics in this study, we primarily focused on the average amplitude of three electrode channels: Cz, CPz, and Pz, for temporal analysis. The LPP was calculated by averaging the amplitudes within the time window of 400 to 800 ms.

2.4.3. PAC analyses

PAC is a commonly used method to investigate coupling phenomena between frequency bands in the brain. There are various calculation methods for PAC, such as Phase Locking Value (PLV), Minimum Vector Length (MVL), Modulation Index (MI), envelope signal correlation, and generalized linear model. Tort et al. conducted the most extensive comparison to date, including most of the methods listed above, and evaluated their performance in terms of noise tolerance, amplitude independence, sensitivity to multimodality, and sensitivity to modulation width [38]. Their results showed that MI received good evaluations in all aspects, while PLV received poor evaluations in all aspects. MVL received favorable evaluations in certain aspects (e.g., noise tolerance) but had weaknesses in other aspects (e.g., amplitude dependence). Therefore, this study utilized MI to measure the degree of PAC. MI is calculated by analyzing the distribution of high-frequency amplitude on the low-frequency phase signal and computing the Shannon entropy of that distribution. The MI value is positively correlated with the strength of low-frequency phase modulation on high-frequency amplitude. The steps for calculating MI in this study are illustrated in Fig. 2c.

To extract the phase, the EEG signals were first bandpass filtered from 0.5 to 30 Hz, and the standard Hilbert transform was applied to extract the phase of the low-frequency component. Similarly, to obtain the amplitude component, the EEG signals were bandpass filtered from 50 to 140 Hz, and the Hilbert transform was used to extract the amplitude from the filtered signal. For each frequency pair, the distribution of the instantaneous amplitude envelope was calculated during each 20° interval of the instantaneous phase, creating 18 phase bins. The average amplitude of each bin was normalized by the sum of the average amplitudes across all bins, resulting in a probability distribution that yields the MI as a measure of coupling strength.

3. Results and discussion

3.1. Results of the scale analysis

In this study, the emotional scores of three groups were analyzed. Table 1 describes the differences in PANAS scores among the three groups during the UG task under NR and CR conditions. From the table, it can be observed that after CR, all three groups showed a decrease in negative emotional experience scores and an increase in positive emotional experience scores. However, compared to HC, SA group exhibited a smaller improvement in negative emotional experience scores.

A 2 (Condition: NR, CR) × 3 (Group) × 2 (Emotion: positive, negative) repeated measures analysis of variance (ANOVA) was conducted to analyze the emotional scores of the three groups. The results showed a significant interaction between condition and emotion ($F(1,74) = 15.92$, $p < 0.01$, $\eta^2 = 0.15$). Simple effect analysis indicated that the positive emotional scores in the DM task were significantly higher than the negative emotional scores under both NR and CR conditions ($p < 0.01$).

The between-group analysis revealed that under the NC, SA group had significantly higher negative emotional experience scores than those of NSA group ($p < 0.05$). After conducting the DM task with CR, SA group still had significantly higher negative emotional experience scores than those of NSA group ($p < 0.05$) and HC ($p < 0.05$). Furthermore, paired-sample t-tests were conducted to analyze the differences in emotional scores under NR and after CR conditions within each group. The results showed that only the HC exhibited a significant increase in positive emotion ($p < 0.05$) and a significant decrease in negative emotion ($p < 0.01$) after CR, while the other two groups did not

Table 1
PANAS scores under NR and CR conditions.

Condition	SA[a]	NSA[b]	HC[c]	Statistic F	*p* value	Post Hoc
NR[d]						
positive	28.23 ± 7.71	28.32 ± 8.12	29.75 ± 5.73	0.28	0.754	
negative	22.20 ± 9.33	16.00 ± 7.53	18.30 ± 4.32	3.78	0.028*	SA > NSA
CR[e]						
positive	29.95 ± 11.1	29.11 ± 9.34	31.25 ± 7.42	0.25	0.778	
negative	20.66 ± 8.99	15.63 ± 6.44	15.40 ± 4.31	4.01	0.02	SA > NSA,HC

[a] SA represent the suicide attempters. [b]NSA represent the non-suicide attempters. [c]HC represent the healthy controls. [d]CR represent the cognitive reappraisal. [e]NR represent the natural responses. M stands for mean, SD stands for standard deviation, and *indicates $p < 0.05$.

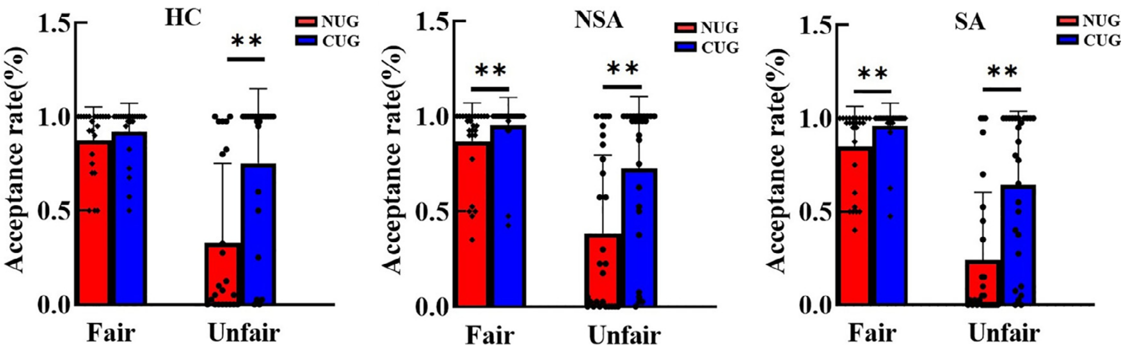

Fig. 3. Acceptance rates of different allocation schemes for three groups of subjects under NR condition and after use of the CR strategy (Natural condition UG: NUG, Cognitive reappraisal UG: CUG). $^{*}p < 0.05$, $^{**}p < 0 .01$.

show significant differences in emotional scores under NR and after CR conditions.

3.2. Results of the behavioral analysis

Fig. 3. presents the results of a repeated measures ANOVA on the acceptance rates for different allocation schemes under NR condition and after the use of ER strategies in the HC/NSA/SA groups. The analysis included a 2 (Condition: NR, CR) × 3 (group) × 2 (allocation scheme) design. We found a significant effect of ER (F(1, 74) = 75.83, $p < 0.01$, $\eta^2 = 0.506$), a significant main effect of allocation scheme (F(2, 73) = 97.78, $p < 0.01$, $\eta^2 = 0.580$), and a significant interaction between ER and allocation scheme (F(2, 73) = 26.66, $p < 0.01$, $\eta^2 = 0.279$). Simple effect analysis revealed that, except for the fair allocation scheme, the acceptance rates significantly increased after CR compared to the NR condition ($p < 0.01$). These results indicated that all three groups were able to effectively utilize CR strategies to improve acceptance rates in the task, but there were no significant differences in acceptance rates among the groups for each allocation scheme under NR and CR conditions.

The reaction times during the DM task was analyzed using repeated measures ANOVA with a 2 (Condition: NR, CR) × 3 (group) × 2 (allocation scheme) design. The results showed non-significant effects for condition, group, and allocation scheme. This suggests that, compared to the NSA group and HC, the SA group did not exhibit significant abnormalities in reaction times during the DM task under NR and after CR conditions.

3.3. Results of the ERP analysis

Fig. 4a depicts the LPP waveforms induced during DM under NR condition and after CR in the three groups. The results of a repeated measures ANOVA with a 2 (Condition: NR, CR) × 3 (group) × 2 (allocation scheme) design showed that neither the interaction effect between condition and groups nor the interaction effect between condition and groups was significant. There were no significant differences in LPP waveforms under NR and after CR conditions, regardless of whether participants were facing a fair or unfair allocation scheme.

Fig. 4b shows within-group differences in LPP amplitudes for the three groups during the task when facing different allocation schemes in both NR and CR conditions. Paired-sample t-test results revealed that only in the SA group, there was a significant increase in LPP amplitude for unfair decisions compared to fair decisions after employing CR ($p = 0.017$). However, such phenomenon was not observed in the NSA group and HC. This indicates that after using CR strategies, SA still exhibit sustained processing of unfair decision-making information and abnormal perception of fairness.

The results of between-group one-way ANOVA on the LPP elicited by different allocation schemes under NR and after CR conditions are shown in Fig. 5. When facing a fair allocation scheme, no significant between-group differences were found in both NR and CR conditions. However, when facing an unfair allocation scheme, the LPP amplitude elicited in the DM task after CR strategies was significantly greater in the SA group compared to the NSA group ($p = 0.025$). The effectiveness of CR strategies in the SA group was lower than that in the NSA group.

3.4. Results of the PAC analysis

The non-parametric Kruskal-Wallis test was employed to analyze within-group differences in PAC under NR and after CR conditions. The results showed no significant differences in TGC among the three groups under NR and after CR conditions. As depicted in Fig. 6, the SA group exhibited a reduction in TGC in the frontal-central region after using CR compared to the NR condition. However, statistical analysis did not reveal significant differences.

Fig. 6b and c illustrate the graphical and statistical results of the differences in TGC after CR strategies among the three groups. Group-level analysis using the non-parametric Kruskal-Wallis test, followed by Bonferroni-corrected post-hoc pairwise comparisons, revealed that after CR, the SA group exhibited a significant reduction in frontal TGC compared to the HC ($p = 0.038$) and the NSA group ($p = 0.023$). Additionally, when compared to the NSA group, the SA group still demonstrated a sig-

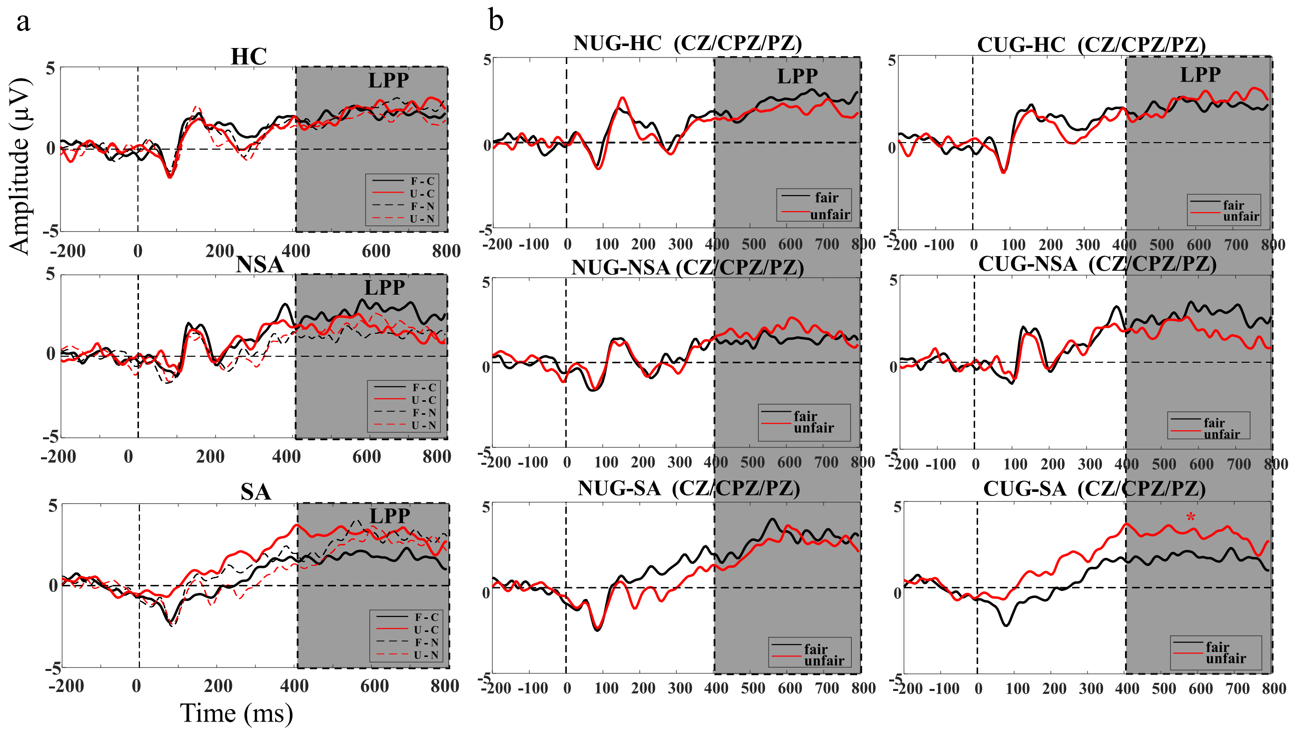

Fig. 4. (a) Results of within-group differences in LPP amplitude under NR and after CR conditions for three groups facing different allocation options (Fair option: F, Unfair option: U, Cognitive reappraisal: C, Natural condition: N). (b) Results of within-group differences in LPP amplitude between the three groups in the NR condition and CR condition in the face of different allocation options. $^{*}p < 0.05$.

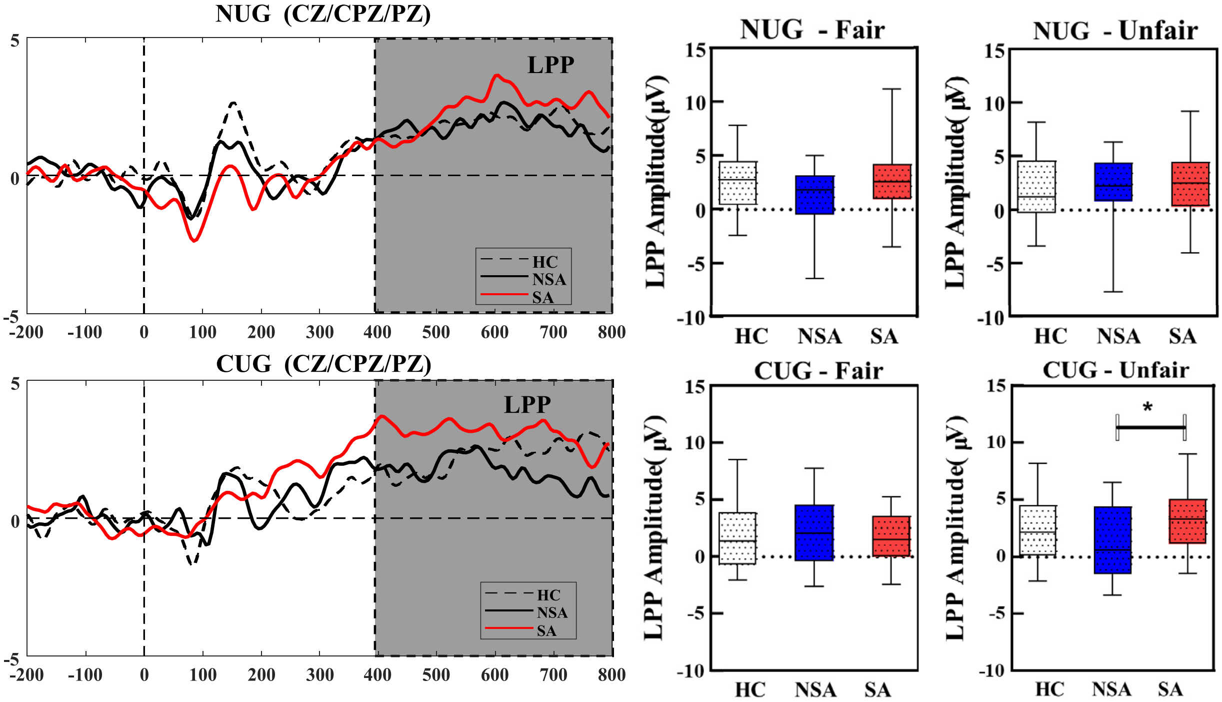

Fig. 5. Results of intergroup differences in LPP amplitudes among the three groups under different allocation schemes under NR and after CR conditions. $^{*}p < 0.05$.

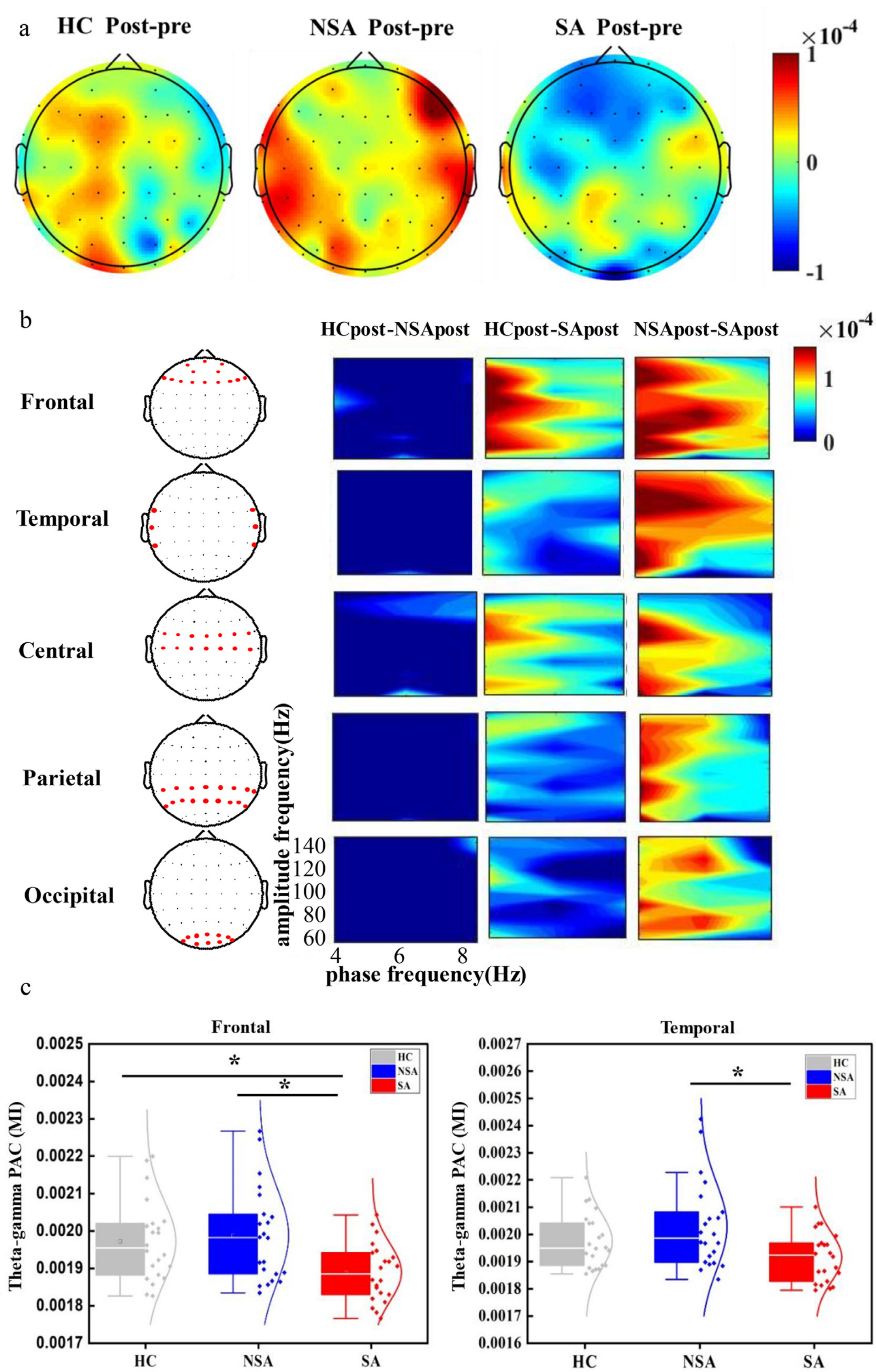

Fig. 6. (a) Results of theta-gamma PAC coupling differences between the three groups under NR and after the CR conditions. (b) Results of the differences in TGC after CR strategies among the three groups. (c) Statistical results of differences in TGC after CR strategies in three groups.

nificant reduction in temporal TGC (p = 0.015). These findings indicate that SA exhibit abnormal TGC in the frontal and temporal regions in both NR and CR condition, suggesting the presence of cognitive impairments in SA.

4. Conclusion

This study primarily investigated the impact of CR, an emotion regulation strategy, on the fairness DM performance of SA. By employing ERP and PAC techniques to extract dynamic EEG characteristics, behavioral and neurophysiological differences were compared among the SA group, NSA group and HC under NR and after CR conditions during the DM process.

Behavioral and scale analysis results showed that the SA group had significantly increased acceptance rates and decreased negative emotion scores after using CR strategy. However, their negative emotion scores remained significantly higher compared to the NSA group and HC. Electrophysiological results indicated no significant differences in LPP amplitudes under NR and after the CR conditions. However, the SA group exhibited a significantly higher LPP amplitude than the NSA group when faced with unfair allocation schemes, reflecting stronger negative emotions when using CR to cope with unfair decisions. It is inferred that the SA group's ability to reduce negative emotions using the CR strategy may be lower than that of the NSA group. Analysis of theta-gamma PAC revealed reduced coupling in the frontotemporal region of the brain in the SA group when faced with unfair allocation schemes. These results objectively measured the impact of the CR emotion regulation strategy on the social DM performance of SA from both behavioral and neurological perspectives. They indicate that the SA group can effectively use the CR strategy to significantly improve acceptance rates behaviorally. However, in terms of electrophysiological indicators, which are more sensitive than behavioral measures, the SA group's ability to use the CR strategy appears lower than that of the NSA group.

Previous neuroimaging studies have identified the neural basis of decision making as a suicide susceptibility trait [14,39]. This study provides a neurophysiological basis for understanding the effects of the CR strategy on the social decision-making performance of suicide attempters and contributes to the research on emotion regulation strategies for preventing suicide.

Declaration of competing interest

The authors declare that they have no conflicts of interest in this work.

Acknowledgments

This work was funded by the STI2030-Major Projects (2021ZD0202000), and the National Natural Science Foundation of China (81925020 and 81801786).

References

[1] World Health O. Suicide Worldwide in 2019: Global Health Estimates, World Health Organization, Geneva, 2021.
[2] K. Sudol, J.J. Mann, Biomarkers of suicide attempt behavior: Towards a biological model of risk, Curr. Psychiatry Rep. 19 (6) (2017) 1–13.
[3] A. Bankwitz, A. Rüesch, A. Adank, et al., EEG source functional connectivity in patients after a recent suicide attempt, Clin. Neurophysiol. 154 (2023) 60–69.
[4] S. Park, Y. Lee, T. Youn, et al., Association between level of suicide risk, characteristics of suicide attempts, and mental disorders among suicide attempters, BMC Public Health 18 (1) (2018) 1–7.
[5] Q. Xiong, F. Tang, Y. Li, et al., Association of inflammatory bowel disease with suicidal ideation, suicide attempts, and suicide: A systematic review and meta-analysis, J. Psychosom. Res. 160 (2022) 110983.
[6] A.L.J.S. Beautrais, L.-T. Behavior, Further suicidal behavior among medically serious suicide attempters, Suicide Life-Threat. Behav. 34 (1) (2004) 1–11.
[7] F. Jollant, N.L. Lawrence, E. Olié, et al., The suicidal mind and brain: A review of neuropsychological and neuroimaging studies, World J. Biol. Psychiatry 12 (5) (2011) 319–339.
[8] F. Jollant, F. Bellivier, M. Leboyer, et al., Impaired decision making in suicide attempters, Am. J. Psychiatry 162 (2) (2005) 304–310.
[9] A. Sastre-Buades, A. Alacreu-Crespo, P. Courtet, et al., Decision-making in suicidal behavior: A systematic review and meta-analysis, Neurosci. Biobehav. Rev. 131 (2021) 642–662.
[10] L. Clark, A.Y. Dombrovski, G.J. Siegle, et al., Impairment in risk-sensitive decision–making in older suicide attempters with depression, J. Psychol. Aging 26 (2) (2011) 321.
[11] A.Y. Dombrovski, L. Clark, G.J. Siegle, et al., Reward/punishment reversal learning in older suicide attempters, Am. J. Psychiatry 167 (6) (2010) 699–707.
[12] S. Richard-Devantoy, M. Berlim, F. Jollant, A meta-analysis of neuropsychological markers of vulnerability to suicidal behavior in mood disorders, Psychol. Med. 44 (8) (2014) 1663–1673.
[13] D. Martino, S. Strejilevich, T. Torralva, et al., Decision making in euthymic bipolar I and bipolar II disorders, Psychol. Med. 41 (6) (2011) 1319–1327.
[14] S.R. Chamberlain, B.L. Odlaug, L.R. Schreiber, et al., Clinical and neurocognitive markers of suicidality in young adults, J. Psychiatr. Res. 47 (5) (2013) 586–591.
[15] J.K. Rilling, B. King-Casas, A.G. Sanfey, The neurobiology of social decision-making, Curr. Opin. Neurobiol. 18 (2) (2008) 159–165.
[16] L. Sánchez-Loyo, E. Ventura-Martínez, A.A. González-Garrido, Decision making in social context in patients with suicide attempt history, Suicide Life-Threat. Behav. 46 (5) (2016) 598–608.
[17] W. Güth, R. Schmittberger, B. Schwarze, An experimental analysis of ultimatum bargaining, J. Econ. Behav. Organ. 3 (4) (1982) 367–388.
[18] Y. Wang, Y. Zhou, S. Li, et al., Impaired social decision making in patients with major depressive disorder, BMC Psychiatry 14 (2014) 1–11.
[19] J.J. Gross, The emerging field of emotion regulation: An integrative review, Rev. Gen. Psychol. 2 (3) (1998) 271–299.
[20] S. Chen, N. Ding, F. Wang, et al., Functional decoupling of emotion coping network subsides automatic emotion regulation by implementation intention, J. Neural Plast. 2021 (1) (2021) 6639739.
[21] E. Ong, C. Thompson, The importance of coping and emotion regulation in the occurrence of suicidal behavior, Psychol. Rep. 122 (4) (2019) 1192–1210.
[22] Y. Song, J.I. Jordan, K.A. Shaffer, et al., Effects of incidental positive emotion and cognitive reappraisal on affective responses to negative stimuli, Cogn. Emotion 33 (6) (2018) 1155–1168.
[23] R.M. Heilman, L.G. Crişan, D. Houser, et al., Emotion regulation and decision making under risk and uncertainty, Emotion 10 (2) (2010) 257.
[24] Y. Fang, X. Huang, X. Wang, et al., Potentiated processing of reward related decision making in depression is attenuated by suicidal ideation, J. Psychiatry Res.: Neuroimaging 332 (2023) 111635.
[25] X. Deng, B. Sang, Y. Ku, et al., Age-related differences in the late positive potential during emotion regulation between adolescents and adults, J. Sci. Rep. 9 (1) (2019) 5738.
[26] G. Hajcak, S. Nieuwenhuis, Reappraisal modulates the electrocortical response to unpleasant pictures, Cogn., Affect., Behav. Neurosci. 6 (4) (2006) 291–297.
[27] A. Keil, M.M. Bradley, O. Hauk, et al., Large-scale neural correlates of affective picture processing, Psychophysiology 39 (5) (2002) 641–649.
[28] F. Bautista, S.E. Macdonald, E.A. Bauer, et al., Generalization of reappraisal to novel negative stimuli as evidenced by the LPP, Int. J. Psychophysiol. 176 (2022) 164–170.
[29] G. Hajcak, A. Macnamara, D.M. Olvet, Event-related potentials, emotion, and emotion regulation: An integrative review, Dev. Neuropsychol. 35 (2) (2010) 129–155.
[30] V. Van Cauwenberge, K. Van Leeuwen, K. Hoppenbrouwers, et al., Developmental changes in neural correlates of cognitive reappraisal: An ERP study using the late positive potential, Neuropsychologia 95 (2017) 94–100.
[31] M. Abubaker, W. Al Qasem, Working memory and cross-frequency coupling of neuronal oscillations 12 (2021) 756661.
[32] B. Yakubov, S. Das, R. Zomorrodi, et al., Cross-frequency coupling in psychiatric disorders: A systematic review, Neurosci. Biobehav. Rev. 138 (2022) 104690.
[33] M.R. Chattun, S. Zhang, Y. Chen, et al., Caudothalamic dysfunction in drug-free suicidally depressed patients: An MEG study, Eur. Arch. Psychiatry Clin. Neurosci. 270 (2020) 217–227.
[34] M. Duan, L. Wang, X. Liu, et al., Abnormal brain activity in fronto-central regions in mental disorders with suicide: An EEG study, in: Proceedings of the 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 2021, p. 2021. F 1-5 Nov.
[35] A. Grecucci, C. Giorgetta, M. Van't Wout, et al., Reappraising the ultimatum: An fMRI study of emotion regulation and decision making, Cerebral Cortex 23 (2) (2012) 399–410.
[36] A. Grecucci, N. De Pisapia, D. Kusalagnana Thero, et al., Baseline and strategic effects behind mindful emotion regulation: Behavioral and physiological investigation, PLoS One 10 (1) (2015) e0116541.
[37] S. Liu, M. Duan, Y. Sun, et al., Neural responses to social decision-making in suicide attempters with mental disorders, BMC Psychiatry 23 (1) (2023) 19.
[38] A.B. Tort, R. Komorowski, H. Eichenbaum, et al., Measuring phase-amplitude coupling between neuronal oscillations of different frequencies, J. Neurophysiol. 104 (2) (2010) 1195–1210.
[39] F. Jollant, N.S. Lawrence, E. Olie, et al., Decreased activation of lateral orbitofrontal cortex during risky choices under uncertainty is associated with disadvantageous decision-making and suicidal behavior, Neuroimage 51 (3) (2010) 1275–1281.

Author profile

Tong Wang is currently a master's student in Medical School of Tianjin University, China. She received her B.S. degree in Biomedical Engineering from Tianjin University in 2021. Her research interests include emotional cognition and neuromodulation.

Xiaoya Liu (BRID: 07099.00.60812) received the Ph.D. degree from Tianjin University, Tianjin, in 2023. She is currently a postdoctoral fellow with the Medical School of Tianjin University. She has been engaged in the analysis and processing of EEG signals for a long time, focusing on the research on neural response characteristics, target identification and regulation technology of depression, bipolar disorder and other mental diseases.

Li An (BRID: 07257.00.03962) is a master's supervisor, practicing psychiatrist, registered supervisor of the Chinese Psychological Society (D-21-013), clinical chief supervisor at the Mental Health Education Center of Tianjin University. With over ten years of experience in college student psychotherapy and psychological crisis intervention, she has accumulated > 5,000 hours in psychotherapy, psychological assessment, and crisis intervention, and over 1,000 hours in supervisory work. Her main research areas are the cognitive psychological mechanisms and intervention techniques of mental disorders, currently focusing on the cognitive neuro mechanisms and intervention techniques of suicide.

Shuang Liu (BRID: 06581.00.70027) a professor and doctoral supervisor, is recognized as a national-level leading talent and the chief scientist of the National Key Research and Development Program. She primarily engages in the research of new theories, technologies, and applications related to emotional brain-computer interfaces, with a focus on engineering applications in significant fields. In recent years, she has led 18 national-level major engineering projects and National Natural Science Foundation projects. She has published over 60 academic papers, obtained 15 national invention patents, undergone substantive examination for 3 invention patents in the United States and Japan, and holds 2 software copyrights.