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Research report

The effectiveness of emotion cognitive reappraisal as measured by self-reported response and its link to EEG alpha asymmetry

Wenjie Li [a,b], Yingjie Li [a,c,*], Dan Cao [a,d]

[a] School of Communication and Information Engineering, Shanghai University, Shanghai 200444, China
[b] School of Information Science and Engineering, Changzhou University, Changzhou, Jiangsu, 213164, China
[c] Shanghai Institute for Advanced Communication and Data Science, Shanghai University, Shanghai, 200444, China
[d] Brainnetome Center and National Laboratory of Pattern Recognition, Institute of Automation, Chinese Academy of Sciences, Beijing 100089, China

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ABSTRACT

Cognitive reappraisal is an important emotion regulation skill for psychological health and well-being, however, some people cannot use this strategy effectively. We investigated EEG alpha asymmetry by calculating lateral index (LI) when twenty-six healthy participants were instructed to complete the emotion cognitive reappraisal task of viewing neutral pictures, watching negative pictures and reappraising negative pictures. According to self-reported valence and arousal, the participants were divided into effective and ineffective groups. Habitual use of rumination was also assessed using the Cognitive Emotion Regulation Questionnaire (CERQ). EEG alpha asymmetry results demonstrated that, ineffective group showed greater relative right temporal activity than effective group in the early stage of reappraisal, indicating higher subjective arousal. Both groups showed greater relative left frontal alpha activity in the late stages of reappraisal compared with watching negative images, indicating the recruitment of corresponding functions in prefrontal regulatory circuitry during the effort of reappraisal. CERQ analysis results showed that, ineffective group got significantly higher score than effective group in habitual use of rumination. Partial correlation revealed that, in male participants, temporal LI change (negative-reappraisal minus negative-watch) was negatively correlated with self-reported arousal and habitual use of rumination. In addition, by using K-means cluster analysis, temporal LI combined with CERQ-rumination score achieved a classification accuracy of 84.6 %. These findings suggested that, EEG alpha asymmetry as well as the habitual use of rumination accounted for the reappraisal effectiveness.

1. Introduction

Reappraisal is one of the emotion regulation strategies that used to change the emotional impact of a situation by altering the meaning or the self-relevance of that situation [1]. In view of positive implications for psychological health, social functioning and well-being [2,3], reappraisal has been widely used in both prevention and intervention of emotion problems. However, it is difficult for some people (especially with emotional disorders) to successfully implement cognitive reappraisal [4–6]. Although numerous studies have investigated the neural mechanisms of reappraisal [7,8], it is unclear why some individuals exhibit ineffective reappraisal.

EEG alpha asymmetry has been extensively investigated in emotional neural science [9–12], showing promising potential in the analysis of emotion regulation. Most research found increased relative left frontal alpha activity not only in automatic emotion regulation [13,14], but also in cognitive reappraisal [8,15]. Parvaz et al. [15] indicated that frontal alpha activity over the left hemisphere was increased during cognitive reappraisal of unpleasant pictures compared with normal viewing. Choi et al. [8] found relative greater left frontal activity when participants were instructed to use reappraisal of negative images than when they normally viewing negative images. In addition, Papousek et al. [16] put forward a concept as "capacity for generating cognitive reappraisals". Participants were instructed to generate as many different ways as possible to reappraise the negative vignettes in Reappraisal Inventiveness Test (RIT [17]), and the numbers and categories of generated ideas were used to index the capacity. Papousek et al. [16] correlated frontal EEG alpha asymmetry with the capacity in generating alternative appraisals of anger-evoking events, finding that individuals with higher capacity had more left-lateralized alpha activity in lateral prefrontal

* Corresponding author at: P.O. Box 98, 99 Shangda Road, Baoshan District Shanghai University, Shanghai 200444, China.
E-mail address: liyj@i.shu.edu.cn (Y. Li).

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cortex. It is reasonable that the higher capacity represents the more possibility of effective cognitive reappraisal, we therefore want to address if effective reappraisal elicit greater relative left alpha activity than ineffective reappraisal.

Previous studies indicated that the generation and alternation of emotion is an evolving time course. Gross [18] proposed a process model of emotion regulation in temporal sequence: (1) selection of the situation, (2) modification of the situation, (3)deployment of attention, (4) change of cognitions, and (5) modulation of experiential, behavioral, or physiological responses. Ochsner et al. [19] then proposed a four-step emotion generation model based on Gross's model, including stimuli in context, attention, appraisal and response. The temporal dynamics of reappraisal was mainly characterized by the event-related potentials (ERP), in which the late positive potential (LPP) during reappraisal has been extensively investigated [20–23]. In our latest ERP research, more positive P200 to negative-watch stimuli relative to both negative-reappraisal and neutral stimuli was found in the failure group in the occipital region, but no such condition differences were observed in the success group. Reappraisal success group showed increased LPP amplitude in negative-reappraisal conditions relative to negative-watch conditions in 3100−5000 ms [24]. Although ERPs have been used to track the neural characteristics of reappraisal success and failure, EEG oscillation and lateralization properties, which were also important for emotion and cognitive reappraisal, have not been well investigated.

The classical EEG alpha asymmetry is usually calculated with the averaged alpha power of all epochs during task engagement [25,14], in which the time-related information within an epoch was lost. In order to examine the dynamic role in the information processing stream, recent studies investigated the time course of frontal alpha asymmetry by dividing EEG data into different time windows according to cognitive process [26,27], which has been widely used in EEG analysis in order to investigate temporal dynamics of brain activity. However, little studies reported the time course of EEG alpha asymmetry during the process of reappraisal.

Additionally, habitual use of emotion regulation strategies (measured by the Cognitive Emotion Regulation Questionnaire, CERQ, [29,30]), has been reported to be related to emotional disorders [31,32] and frontal alpha asymmetry [8]. The increased use of maladaptive strategy coupled with decreased use of adaptive strategy has been proved to be associated with both clinical and subclinical levels of depression and anxiety symptoms [31,32]. In particular, the rumination strategy in CERQ, which refers to repetitively focusing on the negative thoughts and emotions associated with experiences, was found to have unique and significant relationships with depression symptoms [32–35] and cognitive reappraisal process. Ray et al. [36] examined the relation between trait rumination and the neural systems supporting cognitive reappraisal with functional magnetic resonance imaging (fMRI) data, finding that individual differences in rumination correlated with greater decreases in prefrontal regions implicated in self-focused thought when participants were decreasing negative affect. Taken together, rumination seemed to have great influence on emotional disorders and reappraisal neural mechanism. It is significant to explore if the effective reappraisal is also affected by the rumination.

The present study focused on the relationship between EEG alpha asymmetry and the effectiveness of reappraisal, as well as the influence of habitual use of rumination on reappraisal effectiveness. We investigate: (1) the time course of EEG alpha asymmetry during the cognitive control process of reappraisal; (2) whether EEG alpha asymmetry could distinguish effective reappraisal from ineffective reappraisal; (3) whether there is difference in habitual use of rumination between effective reappraisal and ineffective reappraisal; (4)At last, using EEG alpha asymmetry and CERQ-rumination score as features, if effective reappraisal could be distinguished from ineffective reappraisal by cluster analysis.

2. Materials and methods

Data for this analysis came from our recently completed study that utilized ERP to examine characteristics of reappraisal success and failure. See Cao et al. [24] for details.

2.1. Participants

26 graduate students (15 men, 11 women; age range: 21–24 years; all right-handed) recruited from Shanghai University participated in the Experiment. All participants had normal or corrected-to-normal vision, no history of neurological or psychiatric illness, no history of substance or alcohol abuse, and were not taking any prescription medications. According to the self-rating Anxiety Scale (SAS) and self-rating Depression Scale (SDS), all subjects had no depression or anxiety syndrome. All participants signed the informed consent form before the experiment and were paid for participation. The experimental protocol was approved by Shanghai Ethics Committee for Clinical Research. The study was conducted in accordance with the Declaration of Helsinki.

2.2. Stimuli and procedure

Visual stimuli were 90 color images (60 negative, 30 neutral), selected from the International Affective Picture System (IAPS; [37]) according to valence and arousal ratings in the Self-Assessment Manikin (SAM) [38], a 1–9 point Likert scale. Neutral pictures (mean valence = 5.10, SD = 0.38; mean arousal = 3.14, SD = 0.47) contained scenes without positive or negative emotional effect, such as a cup or a book. Negative pictures (mean valence = 2.55, SD = 0.52; mean arousal = 5.75, SD = 0.81) included scenes that brought people unpleasant or discomfort feelings, such as fierce animals or serious disaster. Neutral pictures were used as stimuli for viewing task (neutral-view). Negative pictures were randomly divided into two equal sets, with equated valence and arousal (independent sample *t*-test, p-vales > 0.1), used as stimuli for watching task (negative-watch) and reappraisal task (negative-reappraisal) separately.

The experiment was presented on a color monitor using E-prime 2.0 stimulus presentation software (Psychology software tools, USA). Participants were instructed to view visual stimuli presented on a 17-inch computer monitor placed approximately 70 cm in front of them. Each image occupied approximately 40° of visual angle horizontally and vertically.

The emotion regulation experimental procedure was based on that of Thiruchselvam et al. [39]. The informed consent form was signed by each participant at first, and then a survey of SAS and SDS was completed. Further, the CERQ [29] was conducted to index the extent to which a range of adaptive and maladaptive cognitive strategies were employed to regulate emotion in response to negative stimuli. The experimenter explained the experimental details as follows: two types of images (neutral and negative) would be presented on the monitor, one of the instructions (neutral-view, negative-watch and negative-reappraisal) would be presented before the image. You should respond naturally when doing neutral-view and negative-watch task, and change the way thinking about the image when doing negative-reappraisal task in order to relieve the negative impact, but should not transfer your thoughts to other things that had no relation with the image. In order to ensure good understanding of the task and rules, participants were instructed to complete five practice trials per condition, in which the images were not used in the formal experiment. Participants were given the opportunity to ask questions clarifying the instructions, and were inquired about the details of how they employed the reappraisal strategy after practice. After that, EEG sensors were attached and participants were instructed to attend formal experiment.

The experiment began with an initial period of 3 min rest, 180 s eyes open and 180 s eyes closed. It was designed for subjects' adaptation to the experiment. The emotion regulation task consisted of 3 blocks, each block contained 30 trials equally divided into three conditions: neutral-view, negative-watch and negative-reappraisal. The sequence of the 30 trials within each block was randomized for each participant, and the order of the three blocks was counterbalanced. Participants took a break about 1 min during the interval of blocks. The experimental design for a single trial was illustrated in Fig. 1. Each trial began with a black fixation cross appeared in the center of a grey screen for 2 s, followed by an instruction for 2 s, and then by an image displayed for 5 s against grey background. After the offset of each image, participants rated their level of valence and arousal through button responses. The ratings for both affective dimensions were obtained on a 1–9 scale. For valence, 1 indicated the most negative, and 9 indicated the most positive. For arousal, 1 indicated the calmest, and 9 indicated the most aroused. After button responses, one trial was finished, and then the next.

2.3. EEG measurement and preprocessing

EEG was recorded using SynAmps amplifiers, and digitized with Scan 4.3 software (Neuroscan, Inc.). EEG signals were obtained with standard Ag/AgCl electrodes from 32 sites on the scalp based on the 10–20 system, referenced to the right mastoid and re-referenced offline to the average of the left and right mastoids. Thirty electrodes were selected from 32 electrodes, which cover the whole scalp: FP1, FP2, F3, F4, F7, F8, Fz, FC3, FC4, FCz, FT7, FT8, C3, C4, Cz, T3, T4, CP3, CP4, CPz, TP7, TP8, P3, P4, Pz, T5, T6, O1, O2, Oz. Electrooculography (EOG) electrodes were positioned above and below the left eye as well as the outer canthi of each eye. EEG was continuously recorded at a sampling frequency of 1000 Hz and band-pass filtered from 0.05 Hz to 100 Hz, and inter-electrode impedance was kept below 10 kΩ.

EEG offline preprocessing was conducted with EEGLab (version 12.0.2.6b). EEG data were filtered using a band-pass filter (low cutoff at 0.5 Hz, high cutoff at 80 Hz) and a notch-filter of 50 Hz (low cutoff at 49 Hz, high cutoff at 51 Hz). Artifact rejection was conducted visually on continuous waveforms, with the researcher held blind on condition and participant. Eye-blink and ocular corrections were performed using independent component analysis [40]. Single-trial EEG epochs were extracted for a period beginning 1000 ms prior to image onset and continuing for the entire duration of the image presentation (5000 ms), and each epoch was corrected against a 1000 ms baseline. EEG epochs with artifacts ($> \pm 100$ μV) were excluded.

2.4. Behavioral criteria for the effective and ineffective reappraisal groups

Behavioral criteria for the effective and ineffective reappraisal groups was coincidence with that for the reappraisal success and failure in our previous ERP study [24]. Effective reappraisal is usually defined as the decrease in the ratings of emotional experience when reappraisal is applied to negative images relative to when the negative images are watched only [41,42]. We chose self-reported valence/arousal as the measure of emotional experience, because they are the two orthogonal dimensions of emotional information [43,44], and provide a direct correlate of emotional experience [41]. We defined effective reappraisal as the increase of valence (less negative) and decrease of arousal (less aroused) when applying a cognitive reappraisal strategy to negative images (negative-reappraisal trials) versus respond naturally to negative images (negative-watch trials).

2.5. EEG alpha asymmetry analysis

We conducted EEG asymmetry analysis on artefacts free trials. On average 25 (83.3 %) ± 2.78 (9.3 %) trials remained per condition for effective group, and 26 (86.7 %) ± 2.56 (8.5 %) trials remained per condition for ineffective group.

2.5.1. The classical analysis of EEG alpha asymmetry

The classical EEG alpha asymmetry was calculated in frontal area following the widespread method in previous studies [25,14,8,16]. Spectral power was obtained through a Fast Fourier transform (FFT) for 1-second epochs (Hanning window, 50 % overlap) during image presentation (5 s), and averaged across all artifact-free epochs within each condition (neutral-view, negative-watch and negative-reappraisal). Laterality index (LI) was computed as

$$LI = \ln(P(\text{right})) - \ln(P(\text{left})) \tag{1}$$

where P(right) denotes the mean power of epochs for a right hemisphere electrode, and P(left) denotes that for a homologous left hemisphere electrode [45,46]. In this part, the typically used F3-F4 electrodes were chosen for the calculation as majority of studies did [10,45,47].

2.5.2. Time course analysis of EEG alpha asymmetry

According to the process of emotional processing [20] and our previous ERP study analyzing the same data [24], the analysis was carried out in five time windows after stimulus onset: window 1 (100−200 ms), window 2 (200−300 ms), window 3 (300−1700 ms), window 4

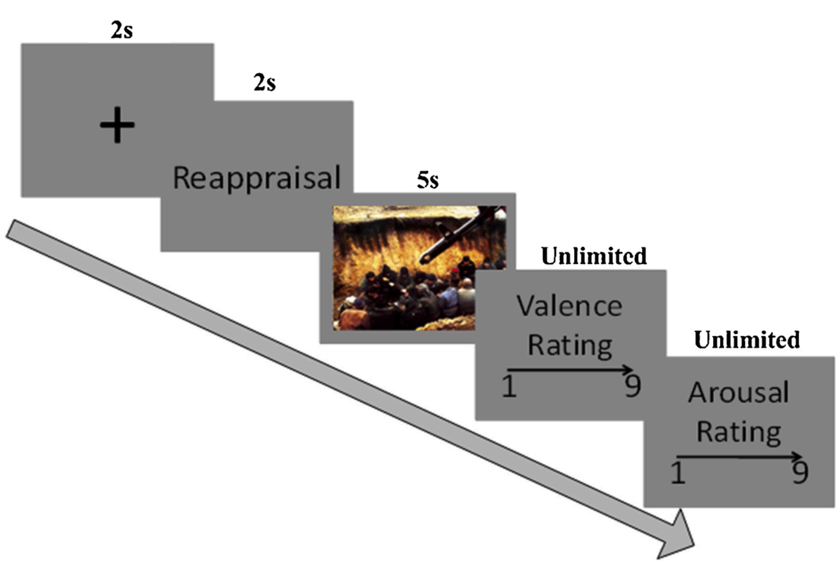

Fig. 1. The experimental design of emotion regulation task for a single trial.

(1700−3100 ms), and window 5 (3100−4800 ms). Alpha activities were subdivided into alpha 1 (8–10 Hz) and alpha 2 (11–13 Hz) due to experimental findings of differential validity [48–51]. Sub-band Powers were extracted using a Db5 wavelet transform in each of the time windows for each condition, and averaged across trials.

In this part, LI was computed as a regional average of LIs (calculated as Eq. (1)) on selected electrode pairs, that is: FP1-FP2, F7-F8, and F3-F4 for frontal area, FC3-FC4 and C3-C4 for central area, FT7-FT8, T3-T4, and TP7-TP8 for temporal area, CP3-CP4 and P3-P4 for parietal area, as well as O1-O2 for occipital area.

Because alpha power has an inhibitory influence on cortical network activity [12], greater EEG alpha asymmetry score, i.e. right alpha power is greater than the left, putatively indicates greater relative left brain activity [25]. As a relative measure, greater EEG alpha asymmetry score reflects either more left than right cortical activity or less right than left cortical activity [12]. As such, in the present study, greater LI score reflected greater relative left activity and vice versa.

2.6. Statistical analysis

2.6.1. Statistics on grouping

For each participant, we conducted independent sample *t*-test of valence and arousal ratings between negative-watch trails and negative-reappraisal trials. If the valence ratings for negative-reappraisal trials were significantly higher (less negative) than that for negative-watch trials ($p < 0.05$), and the arousal ratings for negative-reappraisal trials were significantly lower (less aroused) than that for negative-watch trials ($p < 0.05$), reappraisal was considered a success and the participant was assigned to the effective group. Otherwise, the participant was assigned to the ineffective group. Based on the grouping results, we compared demographic characteristics (e.g. age and education), as well as the SAS and SDS scores between the two groups (independent sample *t*-tests). Besides, by conducting paired sample *t*-tests on the mean valence/arousal (across trials) between negative-watch and negative-reappraisal conditions, we further analyzed the valence/arousal change for each group when reappraisal strategy was applied.

2.6.2. EEG alpha asymmetry

For the classical analysis of EEG alpha asymmetry, we performed repeated-measures analysis of variance (ANOVA) on LI, with Group (2 levels: effective group, ineffective group) as between-subjects factor and Condition (3 levels: neutral-view, negative-watch, and negative-reappraisal) as within-subject factor.

For time course analysis of EEG alpha asymmetry, three-factor (condition*area*group) mixed model multivariate analyses of variance (MANOVA) with repeated measures were used to determine the effect of conditions on alpha 1 and alpha 2 LI between the two groups in each time window. Univariate follow-ups were performed following significant multivariate effects.

For all of the tests, degrees of freedom were corrected by Greenhouse-Geisser when appropriate. Further analysis was performed if any interaction between factors was found. All analyses were conducted at the 0.05 level of significance. Multiple comparisons were corrected by Bonferroni correction.

2.6.3. CERQ scores

In order to investigate the score difference of cognitive emotion regulation strategies between effective and ineffective group and its possible influence on the effectiveness of cognitive reappraisal, the independent sample *t*-tests were performed between groups on the scores of nine conceptually distinct subscales: self-blame, other-blame, rumination, catastrophizing, putting into perspective, positive refocusing, positive reappraisal, acceptance, and planning. All analyses were conducted at the 0.05 level of significance. Gender differences were also examined (independent sample *t*-test).

2.6.4. Partial correlation

When the *group* effect was found in EEG alpha asymmetry during reappraisal, we calculated LI difference between conditions (negative-reappraisal minus negative watch), and examined partial correlations (*Group* as control variable) between LI difference and self-reported response (valence and arousal respectively), as well as CERQ scores. Statistical significance was set at $p < 0.05$.

2.7. K-means cluster analysis with LI and CERQ scores

We intended to conduct k-means cluster analysis [52,53] to classify all subjects into two groups. Variables fed into the analysis comprised LI data and CERQ scores. LI data which showed significant group difference unique to negative-reappraisal condition in MANOVA with repeated measures, as well as subscale scores of CERQ which showed significant effect in independent sample *t*-test, were selected as clustering variables and Z-transformed for further analysis. The independent variables were tested for significant correlations using partial correlation (*Group* as control variable). Cluster analysis was firstly conducted with each variable separately, and then with their combination. In order to verify whether LI data and CERQ scores were promising indexes to distinguish ineffective group from effective group, classification sensitivity (effective subjects classified as effective), specificity (ineffective subjects classified as ineffective) and accuracy (all subjects correctly classified) were computed.

3. Results

3.1. Grouping results

Based on self-reported valence and arousal, 13 participants were included in the effective group (male/female = 7/6; mean age = 22.84 ± 0.80) and 13 participants were included in the ineffective group (male/female = 7/6; mean age = 23.00 ± 0.71). The mean years of education for effective group is 16.69 ± 0.48, and that for ineffective group is 16.77 ± 0.60, including primary education, junior secondary education, senior secondary education, university education and postgraduate education. No statistical difference (independent sample *t*-test, $p > 0.05$) was found in both groups in terms of demographic characteristics including age and education, and of the SAS and SDS scores. In effective group, the valence ratings for negative-reappraisal condition were significantly higher than that for negative-watch condition (paired sample *t*-test, $p < 0.001$), and the arousal ratings for negative-reappraisal condition were significantly lower than that for negative-watch condition (paired sample *t*-test, $p < 0.001$). In ineffective group, the valence ratings for negative-reappraisal condition were significantly higher than that for negative-watch condition (paired sample *t*-test, $p = 0.007$), while negative-reappraisal did not reduce the arousal relative to the negative-watch condition (paired sample *t*-test, $p = 0.118$).

3.2. EEG alpha asymmetry results

3.2.1. The classical analysis results

We found a significant main effect of *Condition* ($F(2, 48) = 4.513$, $p = .016$, $\eta^2 = .158$), indicating that LI was significantly higher in neutral-view condition than in negative-watch condition ($p = .031$). Neither the main effect of *group* nor the interaction effect of *Condition*Group* was found.

3.2.2. Time course analysis results

Table 1 shows a summary of the statistical results on LI in the time course analysis of EEG alpha asymmetry.

3.2.2.1. Window 1 (100−200 ms). Multivariate tests revealed a

Table 1
MANOVA and univariate follow-up effects on LI in the time course analysis of EEG alpha asymmetry.

	Win 1		Win 2		Win 3		Win 4		Win 5	
	alp1	alp2	alp1	alp2	alp1	alp2	alp1	alp2	alp1	alp2
Frontal	G_E<G_I		G_E<G_I			G_E<G_I	Rea > Neg	G_E<G_I	Rea > Neg Rea > Neu	
Temporal			Rea: G_E>G_I							

Note. G_E: Effective Group; G_I: Ineffective Group; Neu: Neutral; Neg: Negative; Rea: Reappraisal alp1: alpha 1; alp2: alpha 2.

significant interaction effect of *Area*Group* (Wilks' Λ = .765, F(8, 190) = 3.412, p = .001). Follow-up univariate tests revealed the interaction effect of *Area*Group* (F(4, 96) = 4.569, p = .013, η^2 = .160) for alpha 1 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* was conducted for each area. This analysis suggested significant *Group* effect in the frontal region (F(1, 24) = 6.379, p = .019, η^2 = .210), indicating that the LI of effective group was smaller than that of ineffective group.

3.2.2.2. Window 2 (200−300 ms). Multivariate tests revealed a significant interaction effect of *Condition*Area*Group* (Wilks' Λ = .697, F(16, 382) = 4.726, p < .001). Follow-up univariate tests revealed the interaction effect of *Condition*Area*Group* (F(8, 192) = 7.161, p < .001, η^2 = .230) for alpha 1 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* and a within factor of *Condition* was conducted for each area. We found the effect on *Group* in frontal area (F(1, 24) = 5.409, p = .029, η^2 = .184), indicating that the LI of effective group was smaller than that of ineffective group. We also found an interaction effect of *Condition*Group* in temporal area (F(2, 48) = 9.887, p < .001, η^2 = .292). To follow up on the *Condition*Group* interaction, the independent sample *t*-tests of between-group comparisons were performed for each condition. The LI of effective group was greater than that of ineffective group in negative-reappraisal task (independent sample *t*-test, t = 3.179, p = .004, Fig. 2), while no *group* effect was found in negative-watch and neutral-view task.

3.2.2.3. Window 3 (300−1700 ms). Multivariate tests revealed a significant interaction effect of *Area*Group* (Wilks' Λ = .816, F(8, 190) = 2.541, p = .012). Follow-up univariate tests revealed the interaction effect of *Area*Group* (F(4, 96) = 3.678, p = 0.037, η^2 = .133) for alpha 2 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* was conducted for each area. This analysis suggested significant *Group* effect in the frontal region (F(1, 24) = 9.379, p = .005, η^2 = .281), indicating that the LI of effective group was smaller than that of ineffective group.

3.2.2.4. Window 4 (1700−3100 ms). Multivariate tests revealed a significant interaction effect of *Condition*Area*Group* (Wilks' Λ = .827, F(16, 382) = 2.381, p = .002). Follow-up univariate tests revealed the interaction effect of *Condition*Area*Group* (F(8, 192) = 2.994, p = .017, η^2 = .111) for alpha 1 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* and a within factor of *Condition* was conducted for each area. We found the effect on *Condition* (F(2, 48) = 3.831, p = .029, η^2 = .138) in frontal area, indicating that the LI in negative-reappraisal task was higher than that in negative-watch task (p = .047).

Multivariate tests also revealed a significant interaction effect of *Area*Group* (Wilks' Λ = .687, F(8, 190) = 4.898, p < .001). Follow-up univariate tests revealed the interaction effect of *Area*Group* (F(4, 96) = 5.603, p = .008, η^2 = .189) for alpha 2 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* was conducted for each area. This analysis suggested significant *Group* effect in the frontal region (F(1, 24) = 8.882, p = .007, η^2 = .270), indicating that the LI of effective group was smaller than ineffective group.

3.2.2.5. Window 5 (3100−4800 ms). Multivariate tests revealed a significant interaction effect of *Condition*Area*Group* (Wilks' Λ = .794, F (16, 382) = 2.911, p < .001). Follow-up univariate tests revealed the interaction effect of *Condition*Area*Group* (F(8, 192) = 2.496, p = .037, η^2 = .094) for alpha 1 LI. To follow up on the interaction, the ANOVA with a between factor of *Group* and a within factor of *Condition* was conducted for each area. We found the effect on *Condition* (F(2, 48) = 5.378, p = .008, η^2 = .183) in frontal area, indicating that the LI in negative-reappraisal task was greater than in negative-watch (p = .013) and neutral-view (p = .040) tasks.

3.3. CERQ results

The independent sample *t*-test results showed that, compared with effective group, ineffective group got significantly higher scores in the subscale *rumination* (12.38 ± 1.94 vs. 10.92 ± 1.66, p = .050, Fig. 3). No significant gender difference in CERQ score was found.

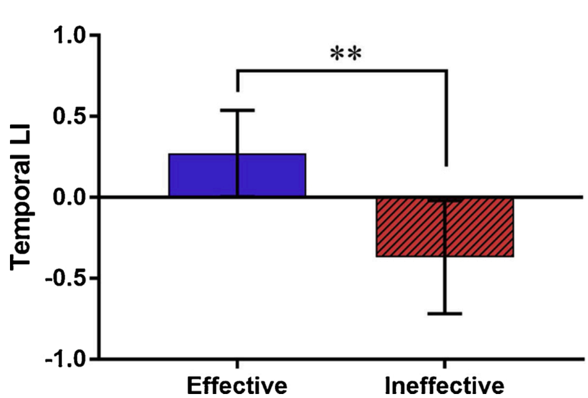

Fig. 2. Comparisons of temporal lateral index (LI) between effective and ineffective group in window 2 (200-300 ms). The LI was averaged across three electrode pairs in temporal region, FT7/8, T3/4, and TP7/8. Error bars represent the 95 % confidence intervals. (**p = .004).

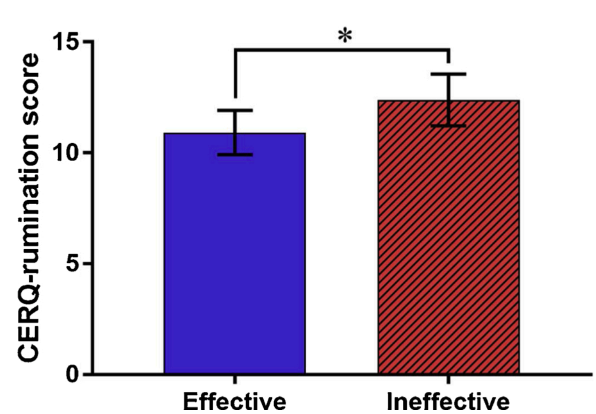

Fig. 3. Comparisons of CERQ-rumination score between effective and ineffective group. Higher score indicates more habitual use of rumination strategy. Error bars represent the 95 % confidence intervals. (*p = .050).

3.4. Partial correlation results

We found the *Group* effect of LI unique to negative-reappraisal condition in temporal area following on the *Condition*Area*Group* interaction in 200−300 ms (section 3.2.2), so the partial correlation was first conducted between temporal LI difference (negative-reappraisal minus negative watch) and self-reported response (valence and arousal respectively). Temporal LI difference did not significantly correlated

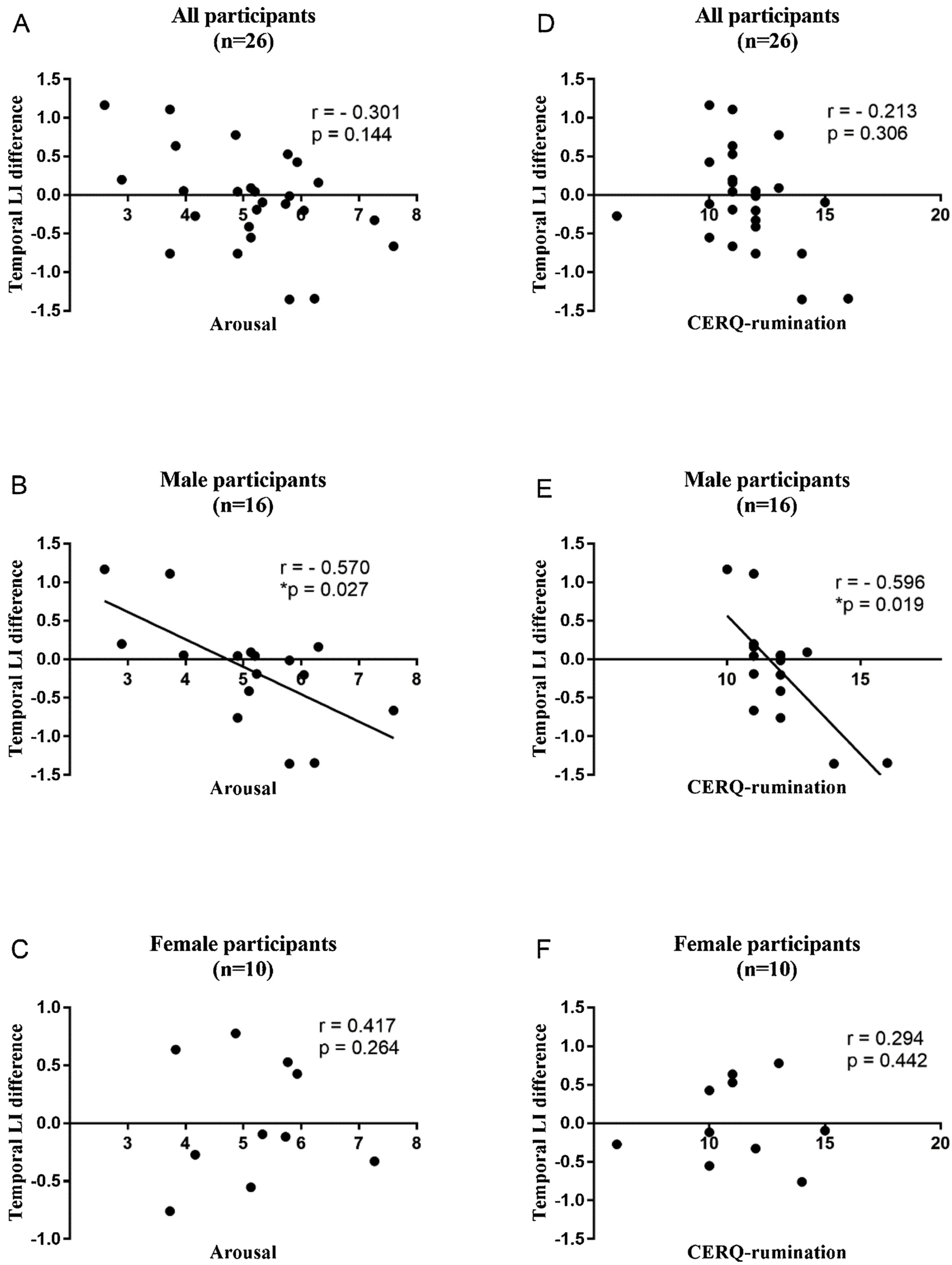

Fig. 4. Partial correlations between temporal lateral index (LI) difference (negative-reappraisal minus negative-watch) and self-reported arousal (A, B, and C) as well as CERQ-rumination scores (D, E, and F). Left column (A, B, and C) shows the partial correlation between the temporal LI changes by reappraisal and self-reported arousal, while right column (D, E, and F) shows the partial correlation between the temporal LI changes by reappraisal and CERQ-rumination scores. Upper row (A and D) shows the partial correlation in all participants, middle row (B and E) shows the partial correlation in male participants, and lower row (C and F) shows the partial correlation in female participants. The *Group* (effective and ineffective) was chosen as the control variable for all the partial correlation.

with self-reported arousal (r = - 0.301, p = 0.144, Fig. 4A). The partial correlation was also tested in male and female participants respectively. The results revealed that temporal LI difference was negatively correlated with self-reported arousal in male participants (r = - 0.570, p = 0.027, Fig. 4B), but not in female participants (r = 0.417, p = 0.264, Fig. 4C). There was no significant correlation between temporal LI difference and self-reported valence.

We also found the *group* effect in the subscale *rumination* of CERQ (section **3.3**), the partial correlation was then conducted between temporal LI difference (negative-reappraisal minus negative watch) and CERQ-rumination score. Temporal LI difference did not significantly correlated with CERQ-rumination score (r = - 0.213, p = 0.306, Fig. 4D). The partial correlation was also tested in male and female participants respectively. The results revealed that temporal LI difference was negatively correlated with CERQ-rumination score in male participants (r = - 0.596, p = 0.019, Fig. 4E), but not in female participants (r = 0.294, p = 0.442, Fig. 4F).

3.5. Cluster analysis results

Temporal LI in window 2 showed significant group difference unique to negative-reappraisal condition. For habitual use of emotion regulation strategy, CERQ-rumination score showed group difference. Consequently, they were adopted as variables for cluster analysis. Partial correlation revealed no significant correlation between temporal LI and CERQ-rumination score. K-means cluster results were presented in Table 2. Temporal LI achieved the classification accuracy of 80.8 %, and rumination score achieved the classification accuracy of 69.2 %. The combination of temporal LI and rumination score correctly classified 12 out of 13 subjects in effective group and 10 out of 13 subjects in ineffective group, resulting in 92.3 % sensitivity, 76.9 % specificity and 84.6 % accuracy. The total accuracy was improved by using combined method than using temporal LI or rumination score alone. The scatter plot of cluster results with the combination of temporal LI and rumination score was presented in Fig. 5.

4. Discussion

EEG alpha asymmetry is examined either at rest as a trait measure [11,54–56], or during emotionally evocative tasks as a state measure [8,15,57]. The state measure of EEG alpha asymmetry is considered to explain more of the variability observed in relevant behavioral outcomes during emotional challenge than trait measure [46,14]. The present study investigated EEG alpha asymmetry as a state measure when participants were instructed to reappraise negative pictures. The classical analysis showed the emotion condition effect without group difference, indicating limited information on whether EEG alpha asymmetry is a dynamic process or where in the cognitive processing stream it may have effects [26,27], and high lightening the demand for time course analysis. The further time course analysis revealed that ineffective group has greater difficulty than effective group in reappraisal, and both groups made great efforts to reappraise the negative stimuli. The cluster analysis showed that LI combined with rumination can be used to identify reappraisal effectiveness.

Table 2
K-means cluster results with temporal LI and rumination score as Features.

Features	Sensitivity (n = 13)	Specificity (n = 13)	Accuracy (n = 26)
LI	76.9 %(10)	84.6 %(11)	80.8 %(21)
Rumination score	69.2 %(9)	69.2 %(9)	69.2 %(18)
LI + Rumination score	92.3 %(12)	76.9 %(10)	84.6 %(22)

Note. Numbers in parentheses represent the number of correctly classified participants.

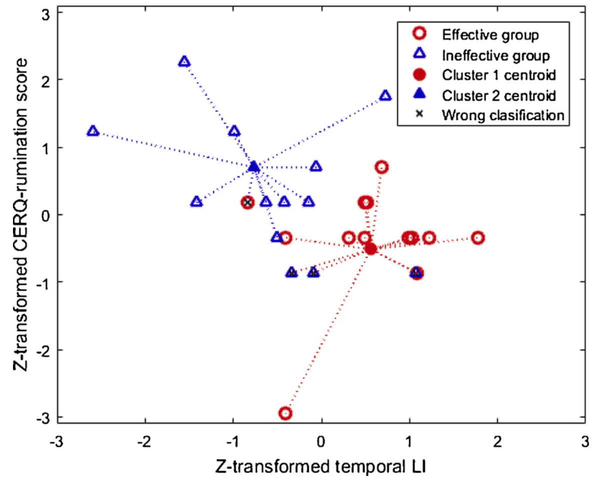

Fig. 5. K-means cluster analysis results with Z-transformed temporal LI and CERQ-rumination score as input variables. The dotted line linked one sample to the centroid indicates that this sample belongs to this cluster.

4.1. No group effect of the classical state measure

In the classical state measure analysis, only the main effect of condition was found. Our results revealed that participants exhibited greater relative right hemisphere activity when being exposed to negative pictures compared with neutral pictures, indicating avoidance/withdrawal motivation [58–60] and negative affective response [14]. No significant difference between neutral-view and negative-reappraisal condition was found, suggesting that the negative impact of the negative stimuli was relieved when reappraisal strategy being used. Counter to our expectations, we found neither the *group* effect between effective group and ineffective group, nor the condition effect between negative-watch and negative-reappraisal. We speculate that the classical analysis is not suitable to account for the reappraisal effectiveness due to its inability to index the time course of neural activity.

4.2. Greater relative right temporal activity on ineffective group in the early stage of reappraisal

Time course analysis revealed that, in the early stage of reappraisal (200−300 ms after stimulus onset), the ineffective group showed greater relative right temporal activity compared with effective group, which was unique to negative-reappraisal condition. Previous studies confirmed that right parieto-temporal region played a critical role during the perception of arousing affective stimuli [61,62], and has been linked to a brain network involving the detection of emotional and reward saliency [63,64]. In the present study, the region where the *group* effect was found partly overlapped with the right temporoparietal region. A recent study further validated that, the particular role of the right temporoparietal region for detecting affective stimulus significance was confined to an early component (N2, about 212 ms) that preceded subcomponents of the late positive complex (P3, LPP) [62]. In our previous ERP study, it was also found that P200 (peak at 200−300 ms) was more positive for negative-watch stimuli compared with both negative-reappraisal and neutral stimuli in the ineffective group [24]. In this study, the *group* effect was found in the same time window (200−300 ms), the early stage of reappraisal.

We deduced that, the greater relative right temporal activity on ineffective group reflects higher subjective arousal to negative stimuli in the early stage of reappraisal. This deduction was further supported by the partial correlation results, showing that reduced relative right temporal activity by reappraisal was negatively correlated with CERQ-rumination score and self-reported arousal in male participants. The results indicated that males who exhibit more habitual use of rumination showed less reduced relative right temporal activity by reappraisal, and males who reduced less relative right temporal activity by reappraisal reported higher arousal, which indicated higher intensity of response [38]. This findings supported previous report that individual differences in rumination correlated with brain activity during reappraisal [36], and provided additional evidence that there were gender differences in the effect of reappraisal on arousal of negative affect [65,66].

Related research indicated that people prefer to choose distractions rather than reappraisal in high-intensity negative situations [67–69]. Even during the initial implementation of reappraisal, high intensity stimuli resulted in increased switching frequency to distraction [70]. Kuo et al. [71] indicated that it is self-reported negative emotional intensity rather than stimulus intensity influences the choice. In our study, although the stimuli were the same for both groups, greater relative right temporal activity on ineffective group indicated higher arousal, and showed that they had more negative feelings to the stimuli in the negative-reappraisal task. We therefore inferred that, if the participants were instructed to use reappraisal strategy when confronting with high intensity stimuli, the effectiveness of the reappraisal would not be guaranteed. Although difficult for some people in high-intensity situations, reappraisal is preferred in low-intensity situations because the engagement with emotional information, which is most beneficial for long-term adaptation [72]. Our findings suggested the necessity of selecting appropriate intensity of stimulus materials for reappraisal training and disorder rehabilitating.

4.3. Greater relative left frontal alpha activity in the late stages of reappraisal

In the late stages (1700−3100 ms and 3100−4800 ms after stimulus onset), the results indicated greater relative left frontal activity in the negative-reappraisal task than in the negative-watch task, both for effective and ineffective group. Choi et al. [8] also reported relative greater left frontal activity when participants were instructed to use reappraisal of negative images than when they normally viewing, and suggested that greater relative left frontal activity was related to the decreased emotional response. However, in the present study, although ineffective group showed greater left frontal activity in negative-reappraisal task, the emotional response was not significantly reduced according to self-reported valence and arousal. Parvaz et al. [15] found increased left frontal activation (decreased alpha power) during reappraisal of negative pictures compared to normal viewing, and inferred an enhancement of the cognitive control of emotion. So we deduced that greater relative left frontal activity in the negative-reappraisal task than in the negative-watch task was a reflection of the recruitment of cognitive and control functions in prefrontal regulatory circuitry. In an fMRI study, Johnstone et al. [73] found left-lateralized activity in the prefrontal cortex during a cognitive reappraisal task in healthy individuals, but not depressed patients. It was assumed that, the left-lateralized activity indicated an appropriate or efficient engagement of prefrontal regulatory circuitry. According to this opinion, our results indicated that both effective and ineffective groups recruited the corresponding functions in prefrontal regulatory circuitry during the effort of reappraisal. Different from the study of Johnstone et al. [73] that compared healthy individuals with depressed patients, participants in the present study were all healthy students without depression or anxiety syndrome, so the interpretation of increased left frontal alpha activity in both groups may be appropriate. The finding of increased left frontal alpha activity during cognitive reappraisal validated the theories of EEG alpha asymmetry in emotion regulation.

4.4. Identification of reappraisal effectiveness with cluster analysis

The ineffective group got higher CERQ-rumination score compared with effective group. Rumination was a maladaptive emotion regulation strategy [74,75], showing unique and specific relations with depression symptoms [76]. The group difference we found herein suggested that ineffective group were more inclined to use rumination strategy when confronted with negative affect, indicating the lower emotion regulation capacity. The identification accuracy of cluster analysis with rumination score was good. Moreover, temporal LI revealed more significant group difference (lower p value) than rumination score, and the effect was unique to negative-reappraisal condition. The identification accuracy for cluster analysis with temporal LI was better than that with rumination score. When we combined temporal LI and rumination score, the accuracy was promoted to 84.6 %, suggesting that the combination of EEG alpha asymmetry and habitual use of emotion regulation strategies was promising in addressing the problem of reappraisal effectiveness.

4.5. Clinical implications and applications

Reduced capacity to cognitively regulate emotional responses is a prominent feature of a broad range of major neuropsychiatric disorders [77]. The enhancement of emotion regulation by neurofeedback training can target the essence of the patients' problems [78]. Previous studies have indicated that EEG alpha asymmetry neurofeedback is useful in reducing the negative affect [79], and is an effective treatment for a variety of psychiatric disorders, such as depression and anxiety [80,81]. Our findings of greater relative left frontal alpha activity in 1700−4800 ms during reappraisal supported the aim of neurofeedback protocol in previous studies, which is to increase the frontal alpha asymmetry (computed by subtracting left from right) [79,81].

It has been demonstrated that emotional intensity influences pre-implementation and implementation of reappraisal [72], and reappraisal of high-intensity emotion requires greater cognitive resources [82]. However, few studies have paid close attention to the influence of participants' subjective emotional intensity in neurofeedback training. The current study found greater relative right temporal alpha activity on ineffective group than on effective group in 200−300 ms during reappraisal, indicating higher subjective arousal on ineffective group, which reflected higher intensity of motivational activation [83]. This finding suggested that temporal alpha asymmetry can be used as an individual indicator to select neurofeedback tasks of appropriate difficulty in the initial training, or to adjust the difficulty of the task as the treatment progressed. The difficulty of the task can be manipulated by the stimuli materials, such as the images from the IAPS system with varied valence and arousal [78,83].

Besides, the present study also reported higher rumination score on ineffective reappraisal group. It seemed that the habitual use of rumination strategy was associated with reduced capacity to cognitively regulate emotional responses, which is a common impairment across major neuropsychiatric disorders. Thus, our findings supported the role of rumination as a transdiagnostic mediator of vulnerability and outcome in psychopathology [84,85]. Interventions targeting rumination may enhance the prevention and treatment of emotional disorders.

5. Conclusions and limitations

This study investigated the time course of EEG alpha asymmetry during the cognitive control process of reappraisal, and accounted for the difference of reappraisal effectiveness. In the early stage of reappraisal, greater relative right temporal activity in ineffective group indicated more negative response, which increased the reappraisal difficulty and ultimately led to failure. In the late stages, greater relative left frontal alpha activity on reappraisal compared with negative-watch, indicated the recruitment of cognitive and control functions in prefrontal regulatory circuitry. There was significant difference in habitual use of rumination between effective and ineffective group, indicating more tendency to use rumination when experiencing negative events in ineffective group.

There are some limitations in the present study and new direction can be studied in the future. First, future studies are needed to further examine how neural characteristics vary as a function of stimulus intensity. Second, we did not consider individual differences in reappraisal inventiveness concerning creativity. Reappraisal Inventiveness Test has been used in previous study to assess the reappraisal capability [16,17]. We can use this test in the future study in order to account for the reappraisal inventiveness difference. At last, future studies are required to examine the gender differences.

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CRediT authorship contribution statement

Wenjie Li: Methodology, Software, Validation, Formal analysis, Writing - original draft, Visualization. **Yingjie Li:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Dan Cao:** Investigation, Data curation.

Declaration of Competing Interest

None.

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References

[1] J.J. Gross, Emotion regulation: current status and future prospects, Psychol. Inq. 26 (1) (2015) 1–26, https://doi.org/10.1080/1047840X.2014.940781.
[2] J.J. Gross, Emotion regulation: affective, cognitive, and social consequences, Psychophysiology 39 (3) (2002) 281–291, https://doi.org/10.1017/S0048577201393198.
[3] J.J. Gross, O.P. John, Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being, J. Pers. Soc. Psychol. 85 (2) (2003) 348–362, https://doi.org/10.1037/0022-3514.85.2.348.
[4] M. Milyavsky, D. Webber, J.R. Fernandez, A.W. Kruglanski, A. Goldenberg, G. Suri, J.J. Gross, To reappraise or not to reappraise? Emotion regulation choice and cognitive energetics, Emotion 19 (6) (2019) 964–981, https://doi.org/10.1037/emo0000498.
[5] A.S. Troy, A.J. Shallcross, A. Brunner, R. Friedman, M.C. Jones, Cognitive reappraisal and acceptance: effects on emotion, physiology, and perceived cognitive costs, Emotion 18 (1) (2018) 58–74, https://doi.org/10.1037/emo0000371.
[6] C.M. Perchtold, E.M. Weiss, c. Rominger, A. Fink, H. Weber, I. Papousek, Cognitive Reappraisal Capacity Mediates the Relationship Between Prefrontal Recruitment During Reappraisal of Anger-Eliciting Events and Paranoia-Proneness, Brain Cogn. 132 (2019) 108–117, https://doi.org/10.1016/j.bandc.2019.04.001.
[7] P.R. Goldin, K. McRae, W. Ramel, J.J. Gross, The neural bases of emotion regulation: reappraisal and suppression of negative emotion, Biol. Psychiatry 63 (6) (2008) 577–586, https://doi.org/10.1016/j.biopsych.2007.05.031.
[8] D. Choi, T. Sekiya, N. Minote, S. Watanuki, Relative left frontal activity in reappraisal and suppression of negative emotion: evidence from frontal alpha asymmetry (FAA), Int. J. Psychophysiol. 109 (2016) 37–44, https://doi.org/10.1016/j.ijpsycho.2016.09.018.
[9] R.J. Davidson, Anterior cerebral asymmetry and the nature of emotion, Brain Cogn. 20 (1) (1992) 125–151, https://doi.org/10.1016/0278-2626(92)90065-t.
[10] R.J. Davidson, What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research, Biol. Psychol. 67 (1–2) (2004) 219–234, https://doi.org/10.1016/j.biopsycho.2004.03.008.
[11] E. Jesulola, C.F. Sharpley, V. Bitsika, L. Agnew, P. Wilson, Frontal alpha asymmetry as a pathway to behavioural withdrawal in depression: research findings and issues, Behav. Brain Res. 292 (2015) 56–67, https://doi.org/10.1016/j.bbr.2015.05.058.
[12] S.J. Reznik, J.J.B. Allen, Frontal asymmetry as a mediator and moderator of emotion: an updated review, Psychophysiology 55 (1) (2017), e12965, https://doi.org/10.1111/psyp.12965.
[13] D.C. Jackson, C.J. Mueller, I. Dolski, K.M. Dalton, J.B. Nitschke, H.L. Urry, M. A. Rosenkranz, C.D. Ryff, B.H. Singer, R.J. Davidson, Now you feel it, now you don't: frontal brain electrical asymmetry and individual differences in emotion regulation, Psychol. Sci. 14 (6) (2003) 612–617, https://doi.org/10.1046/j.0956-7976.2003.psci_1473.x.
[14] R.N. Goodman, J.C. Rietschel, L.C. Lo, M.E. Costanzo, B.D. Hatfield, Stress, emotion regulation and cognitive performance: the predictive contributions of trait and state relative frontal EEG alpha asymmetry, Int. J. Psychophysiol. 87 (2) (2013) 115–123, https://doi.org/10.1016/j.ijpsycho.2012.09.008.
[15] M.A. Parvaz, A. MacNamara, R.Z. Goldstein, G. Hajcak, Event-related induced frontal alpha as a marker of lateral prefrontal cortex activation during cognitive reappraisal, Cogn. Affect. Behav. Neurosci. 12 (4) (2012) 730–740, https://doi.org/10.3758/s13415-012-0107-9.
[16] I. Papousek, E.M. Weiss, C.M. Perchtold, H. Weber, V.L. De Assunção, G. Schulter, H.K. Lackner, A. Fink, The capacity for generating cognitive reappraisals is reflected in asymmetric activation of frontal brain regions, Brain Imaging Behav. 11 (2) (2017) 577–590, https://doi.org/10.1007/s11682-016-9537-2.
[17] H. Weber, V. Loureiro de Assunção, C. Martin, H. Westmeyer, F.C. Geisler, Reappraisal inventiveness: the ability to create different reappraisals of critical situations, Cogn. Emot. 28 (2) (2014) 345–360, https://doi.org/10.1080/02699931.2013.832152.
[18] J.J. Gross, The emerging field of emotion regulation: an integrative review, Rev. Gen. Psychol. 2 (3) (1998) 271–299, https://doi.org/10.1037/1089-2680.2.3.271.
[19] K.N. Ochsner, J.A. Silvers, J.T. Buhle, Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion, Ann. N. Y. Acad. Sci. 1251 (1) (2012) E1–E24, https://doi.org/10.1111/j.1749-6632.2012.06751.x.
[20] D. Foti, G. Hajcak, Deconstructing reappraisal: descriptions preceding arousing pictures modulate the subsequent neural response, J. Cogn. Neurosci. 20 (6) (2008) 977–988, https://doi.org/10.1162/jocn.2008.20066.
[21] S. Schönfelder, P. Kanske, J. Heissler, M. Wessa, Time course of emotion-related responding during distraction and reappraisal, Soc. Cogn. Affect. Neurosci. 9 (9) (2013) 1310–1319, https://doi.org/10.1093/scan/nst116.
[22] P.A. Gable, B.D. Poole, Influence of trait behavioral inhibition and behavioral approach motivation systems on the LPP and frontal asymmetry to anger pictures, Soc. Cogn. Affect. Neurosci. 9 (2) (2014) 182–190, https://doi.org/10.1093/scan/nss130.
[23] F. Marmolejo-Ramos, K. Hellemans, A. Comeau, A. Heenan, A. Faulkner, A. Abizaid, A. D'Angiulli, Event-related potential signatures of perceived and imagined emotional and food real-life photos, Neurosci. Bull. 31 (3) (2015) 317–330, https://doi.org/10.1007/s12264-014-1520-6.
[24] D. Cao, Y. Li, M.A. Niznikiewicz, Neural characteristics of cognitive reappraisal success and failure: an ERP study, Brain Behav. 10 (4) (2020) e01584, https://doi.org/10.1002/brb3.1584.
[25] J.J.B. Allen, J.A. Coan, M. Nazarian, Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion, Biol. Psychol. 67 (1–2) (2004) 183–218, https://doi.org/10.1016/j.biopsycho.2004.03.007.
[26] A.J. Ellis, C. Kinzel, G.C. Salgari, S.K. Loo, Frontal alpha asymmetry predicts inhibitory processing in youth with attention deficit/hyperactivity disorder, Neuropsychologia 102 (2017) 45–51, https://doi.org/10.1016/j.neuropsychologia.2017.06.003.
[27] A. Shevorykin, L.M. Ruglass, R.D. Melara, Frontal alpha asymmetry and inhibitory control among individuals with Cannabis use disorders, Brain Sci. 9 (9) (2019) 219, https://doi.org/10.3390/brainsci9090219.
[29] N. Garnefski, V. Kraaij, P. Spinhoven, Negative life events, cognitive emotion regulation and emotional problems, Pers. Individ. Dif. 30 (8) (2001) 1311–1327, https://doi.org/10.1016/S0191-8869(00)00113-6.
[30] N. Garnefski, J. Legerstee, V.V. Kraaij, T. Van Den Kommer, J. Teerds, Cognitive coping strategies and symptoms of depression and anxiety: a comparison between adolescents and adults, J. Adolesc. 25 (6) (2002) 603–611, https://doi.org/10.1006/jado.2002.0507.
[31] N. Garnefski, V. Kraaij, M.V. Etten, Specificity of relations between adolescents' cognitive emotion regulation strategies and internalizing and externalizing psychopathology, J. Adolesc. 28 (5) (2005) 619–631, https://doi.org/10.1016/j.adolescence.2004.12.009.
[32] N. Garnefski, V. Kraaij, Relationships between cognitive emotion regulation strategies and depressive symptoms: a comparative study of five specific samples, Pers. Individ. Dif. 40 (8) (2006) 1659–1669, https://doi.org/10.1016/j.paid.2005.12.009.
[33] N. Garnefski, V. Kraaij, Specificity of relations between adolescents' cognitive emotion regulation strategies and symptoms of depression and anxiety, Cogn. Emot. 32 (7) (2016) 1401–1408, https://doi.org/10.1080/02699931.2016.1232698.
[34] V. Kraaij, N. Garnefski, Coping and depressive symptoms in adolescents with a chronic medical condition: a search for intervention targets, J. Adolesc. 35 (2012) 1593–1600, https://doi.org/10.1016/j.adolescence.2012.06.007.
[35] V. Kraaij, N. Garnefski, Cognitive, behavioral and goal adjustment coping and depressive symptoms in young people with diabetes: a search for intervention targets for coping skills training, J. Clin. Psychol. Med. Settings 22 (1) (2015) 45–53, https://doi.org/10.1007/s10880-015-9417-8.
[36] R.D. Ray, K.N. Ochsner, J.C. Cooper, E.R. Robertson, J.D.E. Gabrieli, J.J. Gross, Individual differences in trait rumination and the neural systems supporting cognitive reappraisal, Cogn. Affect. Behav. Neurosci. 5 (2) (2005) 156–168, https://doi.org/10.3758/cabn.5.2.156.
[37] P.J. Lang, M.M. Bradley, B.N. Cuthbert, International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual, Technical Report A-8. University of Florida, Gainesville, FL, 2008.
[38] M.M. Bradley, P.J. Lang, Measuring emotion: the self-assessment manikin and the semantic differential, J. Behav. Ther. Exp. Psychiatry 25 (1) (1994) 49–59, https://doi.org/10.1016/0005-7916(94)90063-9.

[39] R. Thiruchselvam, J. Blechert, G. Sheppes, A. Rydstrom, J.J. Gross, The temporal dynamics of emotion regulation: an EEG study of distraction and reappraisal, Biol. Psychol. 87 (1) (2011) 84–92, https://doi.org/10.1016/j.biopsycho.2011.02.009.
[40] A. Delorme, S. Makeig, EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis, J. Neurosci. Methods 134 (1) (2004) 9–21, https://doi.org/10.1016/j.jneumeth.2003.10.009.
[41] T.D. Wager, M.L. Davidson, B.L. Hughes, M.A. Lindquist, K.N. Ochsner, Prefrontal-subcortical pathways mediating successful emotion regulation, Neuron 59 (6) (2008) 1037–1050, https://doi.org/10.1016/j.neuron.2008.09.006.
[42] M.N. Shiota, R.W. Levenson, Effects of aging on experimentally instructed detached reappraisal, positive reappraisal, and emotional behavior suppression, Psychol. Aging 24 (4) (2009) 890–900, https://doi.org/10.1037/a0017896.
[43] P.J. Lang, The varieties of emotional experience: a meditation on James-Lange theory, Psychol. Rev. 101 (2) (1994) 211–221, https://doi.org/10.1037/0033-295x.101.2.211.
[44] S. Schacter, J. Singer, Cognitive, social, and physiological determinants of emotional states, Psychol. Rev. 69 (1962) 379–399, https://doi.org/10.1037/h0046234.
[45] J.A. Coan, J.J.B. Allen, Frontal EEG asymmetry as a moderator and mediator of emotion, Biol. Psychol. 67 (1–2) (2004) 7–49, https://doi.org/10.1111/psyp.12965.
[46] J.A. Coan, J.J. Allen, P.E. Mcknight, A capability model of individual differences in frontal EEG asymmetry, Biol. Psychol. 72 (2) (2006) 198–207, https://doi.org/10.1016/j.biopsycho.2005.10.003.
[47] D.J. Smit, D. Posthuma, D.I. Boomsma, E.J. De Geus, The relation between frontal EEG asymmetry and the risk for anxiety and depression, Biol. Psychol. 74 (1) (2007) 26–33, https://doi.org/10.1016/j.biopsycho.2006.06.002.
[48] I. Papousek, G. Schulter, Covariations of EEG asymmetries and emotional states indicate that activity at frontopolar locations is particularly affected by state factors, Psychophysiology 39 (3) (2002) 350–360, https://doi.org/10.1017/s0048577201393083.
[49] T.S. Hale, S.L. Smalley, G. Hanada, J. Macion, J.T. McCracken, J.J. McGough, S. K. Loo, Atypical alpha asymmetry in adults with ADHD, Neuropsychologia 47 (10) (2009) 2082–2088, https://doi.org/10.1016/j.neuropsychologia.2009.03.021.
[50] S. Ohmatsu, H. Nakano, T. Tominaga, Y. Terakawa, T. Murata, S. Morioka, Activation of the serotonergic system by pedaling exercise changes anterior cingulate cortex activity and improves negative emotion, Behav. Brain Res. 270 (2014) 112–117, https://doi.org/10.1016/j.bbr.2014.04.017.
[51] E.E. Smith, L. Zambrano-Vazquez, J.J.B. Allen, Patterns of alpha asymmetry in those with elevated worry, trait anxiety, and obsessive-compulsive symptoms: a test of the worry and avoidance models of alpha asymmetry, Neuropsychologia 85 (2016) 118–126, https://doi.org/10.1016/j.neuropsychologia.2016.03.010.
[52] N.J. Williams, S.J. Nasuto, J.D. Saddy, Method for exploratory cluster analysis and visualisation of single-trial ERP ensembles, J. Neurosci. Methods 250 (2015) 22–33, https://doi.org/10.1016/j.jneumeth.2015.02.007.
[53] L. Rogenmoser, N. Zollinger, S. Elmer, L. Jäncke, Independent component processes underlying emotions during natural music listening, Soc. Cogn. Affect. Neurosci. 11 (9) (2016) 1428–1439, https://doi.org/10.1093/scan/nsw048.
[54] J.J.B. Allen, M.X. Cohen, Deconstructing the "resting" state: exploring the temporal dynamics of frontal alpha asymmetry as an endophenotype for depression, Front. Hum. Neurosci. 4 (2010) 232, https://doi.org/10.3389/fnhum.2010.00232.
[55] L.B. Neal, P.A. Gable, Regulatory control and impulsivity relate to resting frontal activity, Soc. Cogn. Affect. Neurosci. 12 (9) (2017) 1377–1383, https://doi.org/10.1093/scan/nsx080.
[56] J.L. Stewart, J.J.B. Allen, Resting frontal brain asymmetry is linked to future depressive symptoms in women, Biol. Psychol. 136 (2018) 161–167, https://doi.org/10.1016/j.biopsycho.2018.06.004.
[57] J.L. Stewart, J.A. Coan, D.N. Towers, J.J.B. Allen, Frontal EEG asymmetry during emotional challenge differentiates individuals with and without lifetime major depressive disorder, J. Affect. Disord. 129 (1–3) (2011) 167–174, https://doi.org/10.1016/j.jad.2010.08.029.
[58] R.J. Davidson, Cerebral asymmetry and emotion: conceptual and methodological conundrums, Cogn. Emot. 7 (1993) 115–138, https://doi.org/10.1080/02699939308409180.
[59] E. Harmon-Jones, Clarifying the emotive functions of asymmetrical frontal cortical activity, Psychophysiology 40 (6) (2003) 838–848, https://doi.org/10.1111/1469-8986.00121.
[60] H.A. Demaree, D.E. Everhart, E.A. Youngstrom, D.W. Harrison, Brain lateralization of emotional processing: historical roots and a future incorporating "Dominance", Behav. Cogn. Neurosci. Rev. 4 (1) (2005) 3–20, https://doi.org/10.1177/1534582305276837.
[61] W. Heller, M.A. Etienne, G.A. Miller, Patterns of perceptual asymmetry in depression and anxiety: implications for neuropsychological models of emotion and psychopathology, J. Abnorm. Psychol. 104 (2) (1995) 327–333, https://doi.org/10.1037//0021-843x.104.2.327.
[62] J. Kayser, C.E. Tenke, K.S. Abraham, D.M. Alschuler, J.E. Alvarenga, J. Skipper, V. Warner, G.E. Bruder, M.M. Weissman, Neuronal generator patterns at scalp elicited by lateralized aversive pictures reveal consecutive stages of motivated attention, Neuroimage 142 (2016) 337–350, https://doi.org/10.1016/j.neuroimage.2016.05.059.
[63] M. Corbetta, G.L. Shulman, Control of goal-directed and stimulus-driven attention in the brain, Nat. Rev. Neurosci. 3 (3) (2002) 201–215, https://doi.org/10.1038/nrn755.
[64] A. Lutz, A.P. Jha, J.D. Dunne, C.D. Saron, Investigating the phenomenological matrix of mindfulness related practices from a neurocognitive perspective, Am. Psychol. 70 (7) (2015) 632–658, https://doi.org/10.1037/a0039585.
[65] H.M. Ahn, S.A. Kim, I.J. Hwang, J.W. Jeong, H.T. Kim, S. Hamann, S.H. Kim, The effect of cognitive reappraisal on long-term emotional experience and emotional memory, J. Neuropsychol. 9 (1) (2013) 64–76, https://doi.org/10.1111/jnp.12035.
[66] K.H. Yeh, O. Bedford, C.W. Wu, S.Y. Wang, N.S. Yen, Suppression benefits boys in Taiwan: the relation between gender, emotional regulation strategy, and mental health, Front. Psychol. 8 (2017) 135, https://doi.org/10.3389/fpsyg.2017.00135.
[67] G. Sheppes, S. Scheibe, G. Suri, J.J. Gross, Emotion-regulation choice, Psychol. Sci. 22 (11) (2011) 1391–1396, https://doi.org/10.1177/0956797611418350.
[68] G. Sheppes, S. Scheibe, G. Suri, P. Radu, J. Blechert, J.J. Gross, Emotion regulation choice: a conceptual framework and supporting evidence, J. Exp. Psychol. Gen. 143 (1) (2014) 163–181, https://doi.org/10.1037/a0030831.
[69] J.W. Murphy, M.A. Young, Dynamic processes in emotion regulation choice, Cogn. Emot. 32 (8) (2018) 1654–1662, https://doi.org/10.1080/02699931.2017.1419935.
[70] S.D. Ilan, R. Shafir, J.L. Birk, G.A. Bonanno, G. Sheppes, Monitoring in emotion regulation: behavioral decisions and neural consequences, Soc. Cogn. Affect. Neurosci. 14 (12) (2019) 1273–1283, https://doi.org/10.1093/scan/nsaa001.
[71] J.R. Kuo, S. Fitzpatrick, L.H. Krantz, R.J. Zeifman, How do you choose and how well does it work?: the selection and effectiveness of emotion regulation strategies and their relationship with borderline personality disorder feature severity, Cogn. Emot. 32 (3) (2017) 632–640, https://doi.org/10.1080/02699931.2017.1330254.
[72] R. Shafir, N. Schwartz, J. Blechert, G. Sheppes, Emotional intensity influences pre-implementation and implementation of distraction and reappraisal, Soc. Cogn. Affect. Neurosci. 10 (10) (2015) 1329–1337, https://doi.org/10.1093/scan/nsv022.
[73] T. Johnstone, C.M. Van Reekum, H.L. Urry, N.H. Kalin, R.J. Davidson, Failure to regulate: counterproductive recruitment of top-down prefrontal-subcortical circuitry in major depression, J. Neurosci. 27 (33) (2007) 8877–8884, https://doi.org/10.1523/JNEUROSCI.2063-07.2007.
[74] M.L. Andrés, M.C. Richaud de Minzi, C. Castañeiras, L. Canet-Juric, R. Rodríguez-Carvajal, Neuroticism and depression in children: the role of cognitive emotion regulation strategies, J. Genet. Psychol. 177 (2) (2016) 55–71, https://doi.org/10.1080/00221325.2016.1148659.
[75] A. Aldao, S. Nolen-Hoeksema, S. Schweizer, Emotion-regulation strategies across psychopathology: a meta-analytic review, Clin. Psychol. Rev. 30 (2) (2010) 217–237, https://doi.org/10.1016/j.cpr.2009.11.004.
[76] C.C. Epkins, C. Gardner, N. Scanlon, Rumination and anxiety sensitivity in preadolescent girls: independent, combined, and specific associations with depressive and anxiety symptoms, J. Psychopathol. Behav. Assess. 35 (2013) 540–551, https://doi.org/10.1007/s10862-013-9360-7.
[77] A. Zilverstand, M.A. Parvaz, R.Z. Goldstein, Neuroimaging cognitive reappraisal in clinical populations to define neural targets for enhancing emotion regulation. A systematic review, Neuroimage 151 (2017) 105–116, https://doi.org/10.1016/j.neuroimage.2016.06.009.
[78] P. Sarkheil, A. Zilverstand, N. Kilian-Hütten, F. Schneider, R. Goebel, K. Mathiak, fMRI feedback enhances emotion regulation as evidenced by a reduced amygdala response, Behav. Brain Res. 281 (2015) 326–332, https://doi.org/10.1016/j.bbr.2014.11.027.
[79] R. Mennella, E. Patron, D. Palomba, Frontal alpha asymmetry neurofeedback for the reduction of negative affect and anxiety, Behav. Res. Ther. 92 (2017) 32–40, https://doi.org/10.1016/j.brat.2017.02.002.
[80] F. Peeters, M. Oehlen, J. Ronner, J. Os, R. Lousberg, Neurofeedback as a treatment for major depressive disorder - a pilot study, PLoS One 9 (3) (2014) e91837, https://doi.org/10.1371/journal.pone.0091837.
[81] S. Wang, I. Lin, S. Fan, Y. Tsai, C. Yen, Y. Yeh, M. Huang, Y. Lee, N. Chiu, C. Hung, P. Wang, T. Liu, H. Lin, The effects of alpha asymmetry and high-beta down-training neurofeedback for patients with the major depressive disorder and anxiety symptoms, J. Affect. Disord. 257 (2019) 287–296, https://doi.org/10.1016/j.jad.2019.07.026.
[82] J.A. Silvers, J. Weber, T.D. Wager, K.N. Ochsner, Bad and worse: neural systems underlying reappraisal of high- and low-intensity negative emotions, Soc. Cogn. Affect. Neurosci. 10 (2) (2015) 172–179, https://doi.org/10.1093/scan/nsu043.
[83] M.M. Bradley, M. Codispoti, B.N. Cuthbert, P.J. Lang, Emotion 1 (3) (2001) 276–298, https://doi.org/10.1037/1528-3542.1.3.276.
[84] M. Luca, Maladaptive rumination as a transdiagnostic mediator of vulnerability and outcome in psychopathology, J. Clin. Med. 8 (3) (2019) 314, https://doi.org/10.3390/jcm8030314.
[85] K.A. McLaughlin, S. Nolen-Hoeksema, Rumination as a transdiagnostic factor in depression and anxiety, Curr. Psychol. 49 (3) (2011) 186–193, https://doi.org/10.1016/j.brat.2010.12.006.