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ORIGINAL ARTICLE

The Emotion-Regulation Benefits of Implicit Reappraisal in Clinical Depression: Behavioral and Electrophysiological Evidence

Jiajin Yuan[1] · Yueyao Zhang[2] · Yanli Zhao[3] · Kexiang Gao[2] · Shuping Tan[3] · Dandan Zhang[1,4,5]

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Abstract Major depressive disorder (MDD) is characterized by emotion dysregulation. Whether implicit emotion regulation can compensate for this deficit remains unknown. In this study, we recruited 159 subjects who were healthy controls, had subclinical depression, or had MDD, and examined them under baseline, implicit, and explicit reappraisal conditions. Explicit reappraisal led to the most negative feelings and the largest parietal late positive potential (parietal LPP, an index of emotion intensity) in the MDD group compared to the other two groups; the group difference was absent under the other two conditions. MDD patients showed larger regulatory effects in the LPP during implicit than explicit reappraisal, whereas healthy controls showed a reversed pattern. Furthermore, the frontal P3, an index of voluntary cognitive control, showed larger amplitudes in explicit reappraisal compared to baseline in the healthy and subclinical groups, but not in the MDD group, while implicit reappraisal did not increase P3 across groups. These findings suggest that implicit reappraisal is beneficial for clinical depression.

Keywords Depression · Implicit emotion regulation · Reappraisal · Late positive potential

Jiajin Yuan, Yueyao Zhang, and Yanli Zhao contributed equally to this work.

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✉ Dandan Zhang
zhangdd05@gmail.com

[1] Institute of Brain and Psychological Sciences, Sichuan Normal University, Chengdu 610066, China

[2] School of Psychology, Shenzhen University, Shenzhen 518060, China

[3] Psychiatry Research Center, Beijing Huilongguan Hospital, Beijing 100096, China

[4] Shenzhen-Hong Kong Institute of Brain Science, Shenzhen 518060, China

[5] Magnetic Resonance Imaging (MRI) Center, Shenzhen University, Shenzhen 518060, China

Introduction

Depression is a common mental disorder characterized by difficulties in emotion regulation [1–3]. The onset of depression is often coupled with frequent use of emotion-focused rumination [4–10], reduced use of adaptive strategies for emotional down-regulation such as cognitive reappraisal [1, 11], and frequent use of a maladaptive strategy that enhances negative thinking [7, 12]. In line with this evidence, it has been reported that depressed individuals are less able to reduce negative affect through instructed reappraisal than healthy controls [13, 14], and this corresponds to hypoactivity in prefrontal regions and hyperactivity in the amygdala [1, 15, 16].

One important mechanism underlying this phenomenon is that depressive symptoms (e.g., sustained depressed mood) deplete cognitive resources, which consequently impair cognitive functions including executive control, memory, and attention in depressive patients [17–22]. However, the intentional use of adaptive strategies for emotional regulation, either initiation or maintenance of a strategy, entails top-down cognitive control mechanisms and the consumption of cognitive resources [23–25], as shown by enhanced activation in the frontoparietal cognitive network [26]. Consistent with this inference, recent studies suggest that the reduced use of reappraisal in depressive patients can be explained, at

least in part, by the fact that intentional strategy use drains their already limited cognitive resources [27]. The inability to regulate negative affect predisposes depressed individuals to sustained negative affect and difficulties in the experience of positive affect, which in turn exacerbate depressive symptoms [1]. Therefore, it is critical to seek an alternative, less resource-costly strategy for the rehabilitation of emotion-regulatory function in depression.

In line with this theme, implicit emotion regulation (also called nonconscious or automatic emotion regulation) is a goal-driven change to one's emotion without explicit instruction or deliberate control or even in the absence of a conscious decision [28]. Previous research has shown that, compared with explicit emotion regulation, implicit emotion regulation works for the reduction of negative emotion at little or no cost of cognitive resources [29–31]. According to previous electrophysiological findings, implicit emotion regulation does not increase the amplitude of frontal P3 (an index of cognitive control) when participants down-regulate their negative emotions [32]. Similarly, neuroimaging evidence has shown that implicit emotion regulation can decrease the activation in the amygdala and insula while it does not increase the activation in the frontoparietal control network [26]. Given that depressive patients are characterized by self-depletion and the resultant deficit in voluntary emotion regulation [27, 33–35], it is possible that implicit emotion regulation, an effortless, resource-saving process, is a more suitable strategy for depressive patients to realize the efficient regulation of depressive emotions. In previous studies, priming techniques have always been used to manipulate implicit regulatory processes [36–40]. For instance, Yuan *et al*. primed acceptance strategy and found implicit emotion regulation reduced emotional experience without enhancing cognitive effort [41]. More relevant to the current study, a recent study on subclinical depression reported that implicit priming of distraction protected depressed individuals from positive affect reduction during frustration, while explicit distraction did not have this effect [34]. As the evidence consistently shows that the implicit method of emotion regulation can reduce negative emotions in healthy and subclinical depressive populations, it is possible that this approach also works in emotion regulation in clinical depression. However, no study has directly tested this possibility to date.

Using behavioral and event-related potential techniques, the current study aimed at exploring the intervention effects of implicit emotion regulation on clinical depression. Three groups of subjects were included, that is, patients diagnosed with major depressive disorder (MDD), participants with subclinical depression, and healthy control participants. The subclinical depression group was included to help depict the trajectory of how emotion-regulatory effects of explicit and implicit reappraisal vary as a function of depression severity. Self-reporting is one of the most-used tools with which to assess emotion, as it directly reflects one's currently-experienced emotions. However, there is evidence that the validity of self-reports is affected by the expectation of explicit instruction [42–44]. By contrast, event-related potentials (ERPs) are direct measures of brain activity and can be used as objective and sensitive indexes of the emotion regulation effect [45, 46]. Specifically, the late positive potential (LPP) in the parietal scalp region is a reliable measure indicating the emotional intensity and motivational salience of a stimulus [47, 48]. Previous studies have consistently shown that the down-regulation of negative emotion reduces the LPP amplitude [49–52]. Hence, our study applied two indices to measure emotion regulation effects: subjective rating and LPP amplitude. Meanwhile, the frontally-peaking late-positive component during an emotion-regulation task is accepted as an index of resource involvement in effortful control [53–55]. Voluntary inhibition of negative emotion *via* cognitive reappraisal or expressive suppression enhances the LPP amplitude, named either frontal-central P3 [56, 57] or frontal LPP [55, 57]. This control-related frontal component is reported to be more pronounced during explicit *versus* implicit regulation of negative emotion [53]. Therefore, in the current study, we were also interested in how the frontally-peaking late positive component varies across conditions to clarify how cognitive-control processes involved in emotion regulation differ with regulatory methods and depression severity.

We chose cognitive reappraisal as the target strategy as it is considered more reliable in emotion down-regulation than other strategies [58]. Also, reappraisal is a key component in depression-related cognitive therapies such as cognitive-behavioral therapy and dialectical behavioral therapy [59, 60]. Given the fact of insufficient cognitive resources, we speculated that depressive patients may find it difficult to regulate unpleasant emotions *via* intentional reappraisal [27, 33–35]. Instead, due to the automatic, resource-saving characteristics of implicit emotion regulation, we assumed that depressive patients may benefit from the use of implicit reappraisal in terms of emotion regulation. Exploration of this issue may provide a new avenue for the treatment of depression.

Materials and Methods

Participants

Sample size estimation is reported in the Supplementary Material (Part A). Patients were recruited from Beijing Huilongguan Hospital. They were diagnosed with a current major depressive episode according to the Diagnostic and Statistical Manual (DSM-IV) [61]. The diagnosis was based on a structured clinical interview for DSM-IV (SCID-I/P

W/PSY SCREEN) [62]. Exclusion criteria for patients were current or lifetime neurological disorders and any comorbid Axis I disorder. At the time of the experiment, all patients were either untreated with any antidepressant medication, or had undergone a wash-out period of at least two weeks. Subthreshold depression (SD) and control participants were recruited through advertisements in the community around Beijing Huilongguan Hospital. Exclusion criteria for these two groups were neurological disorders and any lifetime Axis I disorders according to the structured clinical interview for DSM-IV Axis I Disorders, Non-Patient edition (SCID-I/NP) [63]. Both patients and SD subjects were additionally required to have a score of ≥14 on the Beck Depression Inventory Second Edition (BDI-II) [64], while controls should have a BDI-II score of <14. Written informed consent was obtained prior to the experiment. All procedures in this study were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee of Beijing Huilongguan Hospital (# 2020-0127).

Participants were required to complete four questionnaires on the day of the experiment: (1) the BDI-II, (2) the Trait form of Spielberger's State-Trait Anxiety Inventory (STAI-T) [65], (3) the cognitive reappraisal dimension of Emotion Regulation Questionnaire (ERQ-R) [66], and (4) the reappraisal subscale of the Thought Control Questionnaire (TCQ-R) [67] (Table 1). Among them, the BDI-II consists of 21 items ranging from 0 to 3, with a higher score indicating more depressive symptoms. The STAI-T consists of 20 items ranging from 1 to 4, with a higher score indicating a higher level of trait anxiety. The ERQ-R assesses 6 items of the tendency to use a cognitive reappraisal strategy to regulate emotions, ranging from 1 (strongly disagree) to 7 (strongly agree). The TCQ-R is a 6-item scale ranging from 1 to 4, with a higher score indicating a greater extent of use of cognitive reappraisal to control thoughts.

Experimental Design and Procedure

The study had a 3 × 3 mixed design. The within-subject factor was the condition (baseline, implicit and explicit emotion regulation), and the between-subject factor was the group (control, SD, and depressed patient).

The experiment was conducted from 09:00 to 12:00 or 15:00 to 21:00 and the experiment time was matched across the three groups. There were three blocks in the experiment (Fig. 1A), whose order was fixed (i.e., baseline first, then the implicit, followed by the explicit condition) to ensure that the baseline condition was not disturbed by the other two emotion regulation blocks, and the implicit regulation block was not interfered with by the explicit emotion regulation instructions [49]. After the first two blocks, instructions were given to participants to explicitly regulate their emotions using cognitive reappraisal. The three 10-min blocks were separated by two 5-min breaks, resulting in a task time of 40 min. The potential influence of block order was examined in a separate experiment, which revealed a non-significant order effect (Supplementary Material, part B).

In each block, participants performed a word-matching (40 trials per block) and a dot-counting task (50 trials per block). The word-matching task was designed to non-consciously operate emotion regulation goals by priming reappraisal on outcome evaluation [32, 38, 40], while the dot-counting task (rapid dot-counting combined with negative

Table 1 Demographic characteristics of the participants (mean and standard deviation)

Items	Control (C)	Subthreshold (SD)	Patient (P)	Statistics [a]
Sample size	54	52	53	$\chi^2_{(2)} = 0.0$, $P = 0.981$
Gender (male/female)	24/30	22/30	22/31	$\chi^2_{(2)} = 0.1$, $P = 0.951$
Age (years)	29.0 (6.5)	28.7 (7.4)	30.8 (6.4)	$F_{(2, 156)} = 1.5$, $P = 0.218$
Handedness (right/left)	54/0	52/0	53/0	
Education (years)	17.5 (4.2)	16.6 (3.0)	16.2 (2.8)	$F_{(2, 156)} = 2.1$, $P = 0.126$
BDI-II	2.2 (2.0)	20.0 (5.2)	26.3 (7.8)	$F_{(2, 156)} = 273.4$, $P < 0.001$, C < SD < P
STAI-T	35.5 (6.5)	53.1 (6.6)	61.4 (7.2)	$F_{(2, 156)} = 205.9$, $P < 0.001$, C < SD < P
ERQ-R	30.0 (4.7)	26.4 (5.8)	25.4 (5.6)	$F_{(2, 156)} = 11.1$, $P < 0.001$, C > SD/P
TCQ-R	15.3 (3.3)	13.8 (3.5)	12.3 (3.3)	$F_{(2, 156)} = 10.3$, $P < 0.001$, C > P
HRSD			21.3 (5.7)	
Age at onset (years)			29.1 (10.1)	
Duration of illness (months)			18.3 (22.2)	
Number of episodes			0.3 (0.8)	

BDI-II, Beck Depression Inventory Second Edition; STAI-T, Trait form of Spielberger's State-Trait Anxiety Inventory; ERQ-R, the cognitive reappraisal dimension of the Emotion Regulation Questionnaire; TCQ-R, the reappraisal subscale of the Thought Control Questionnaire; HRSD, Hamilton Depression Rating Scale. [a] The χ^2 test was applied to categorical variables. Univariate analysis of variance was applied to continuous variables, with the group as the fixed factor (Bonferroni correction).

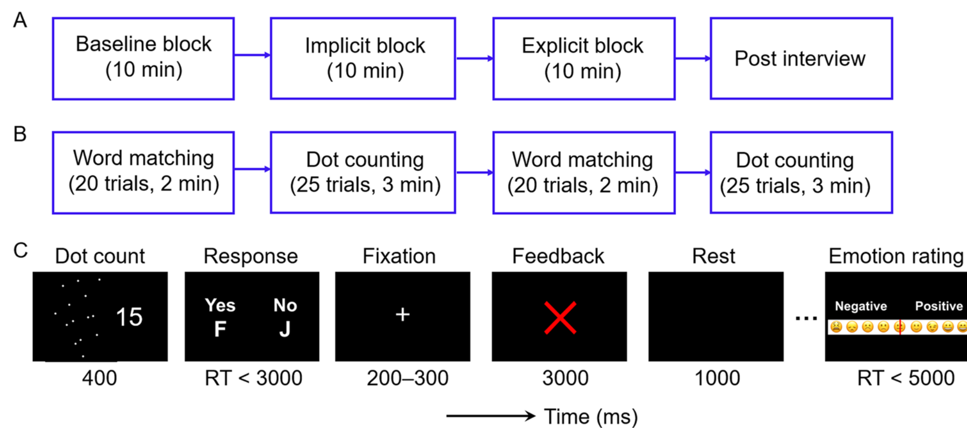

Fig. 1 Experimental procedures. **A** Flowchart of the experiment. The order of the three blocks is fixed to ensure that the baseline condition is not disturbed by the other two emotion regulation blocks, and that the implicit regulation block is not interfered with by the explicit emotion regulation instructions. **B** Task order in each block. **C** An exemplar trial containing negative feedback in the dot-counting task. The requirement of emotion rating appears every 10 trials and participants report their emotions on a scale of 1–9. RT, response time.

feedback) was designed to induce depressive emotions in participants [34, 37]. These two tasks were split into four alternately-presented mini-tasks to ensure the effect of priming (Fig. 1B).

In each trial of word-matching, participants chose one out of two optional words and matched its meaning to that of the target word. In the implicit regulation block, the target word and one of the optional words were reappraisal-related items, whereas, in the baseline and explicit regulation blocks, all three words were items unrelated to emotion-regulation. It was hypothesized that the process of matching two reappraisal-related words could activate the goal of regulating the subsequent emotional response through cognitive reappraisal, while matching two words unrelated to emotion-regulation did not influence emotion regulation.

In each trial of dot counting (Fig. 1C), a picture containing randomly-distributed dots was present for 400 ms, and participants were required to judge, within 3 s, whether the number of dots matched a given number presented on the right side of these dots. Then the outcome feedback was presented for 3 s, indicating correct (a green tick) or incorrect responses (a red cross). The outcome feedback was pseudo-randomly produced by the program, including 36 incorrect outcomes (valid trials) and 14 correct ones (fillers) in each block. Furthermore, subjects were also required, in the baseline and implicit reappraisal conditions, to pay close attention to the feedback and experience emotion naturally. In the explicit feedback, subjects were required to reinterpret the meanings of the negative feedback to down-regulate unpleasant emotions, such as "the picture duration and time of answering are both too short, and other people may not answer correctly as well". To ensure that all participants understood and could follow the instructions without difficulty, they were given enough time to practice reappraising the sample pictures. Also, they were required to explain the explicit instructions before the explicit block. Experimenters reviewed the verbal response of each participant to ensure that they implemented an intended process of cognitive reappraisal.

Lastly, the "emotion rating" requirement was presented in every 10 trials following feedback, during which participants reported their emotions on a 1–9-point scale (1 denotes most unpleasant and 9 denotes most pleasant feelings) by clicking the mouse. There were 5 emotion rating requirements per block, of which 4 followed incorrect (valid) and 1 followed correct feedback (the filler).

A brief interview was conducted after the task to find out how participants felt when they received negative feedback. As a result, 92% (145/159) of participants reported they felt regretful or sad, and the other 8% of participants mentioned that they felt angry besides regretful/sad.

Electroencephalogram (EEG) and emotion rating data were collected during the dot-counting task. We used 20 reappraisal and 70 neutral idioms/phrases in the word-matching task [32, 38, 40]. The reappraisal items had meanings highly related to cognitive reappraisal, while the neutral items did not imply emotion regulation including cognitive reappraisal (Part C of Supplementary Material).

EEG Recording and Analysis

Brain electrical activity was recorded by a 32-channel wireless amplifier with a sampling frequency of 250 Hz (NeuSen. W32, Neuracle, Changzhou, China). Data were recorded on-line referentially against the left mastoid and off-line re-referenced to the average of the left and right mastoids. The recorded data were then filtered off-line (0.01–20 Hz) and segmented beginning 200 ms prior to outcome presentation

and lasting for 3.5 s. Epochs were baseline-corrected (−200 to 0 ms) followed by averaging in each condition.

This study focused on the frontal P3 and parietal LPP components. The frontal P3 was measured as the average amplitude across the electrode sites at and around FCz (FC1, FC2, Fz, F3, and F4). An *a priori* time window for the P3 amplitude (300–600 ms after outcome onset) was chosen according to previous literature [68, 69]. The parietal LPP was measured as the average amplitude across the electrode sites at and around Pz (P3, P4, Pz, CP1, and CP2). An *a priori* time window for the LPP amplitude was chosen according to previous literature [49, 51, 70]. This window began at the end of the typical P3 time window and lasted for the entire emotional regulation period (500–3000 ms after outcome onset).

Results

Subjective ratings of emotional feelings and the event-related potential (ERP) amplitudes were analyzed only in "incorrect" trials. A full report of results is in Supplementary Material Part D. Here we only report the most important findings.

Emotion Rating

Repeated-measures analyses of variances (ANOVA, Greenhouse-Geisser-corrected) revealed significant main effects of the group [$F_{(2, 156)} = 11.6$, $P < 0.001$, $\eta_p^2 = 0.129$; patient < control/SD] and condition [$F_{(2, 312)} = 297.2$, $P < 0.001$, $\eta_p^2 = 0.656$; explicit > implicit > baseline] and significant interaction of condition × group [$F_{(4, 312)} = 26.5$, $P < 0.001$, $\eta_p^2 = 0.253$; Fig. 2A]. Simple effect analysis (Bonferroni method) revealed that the emotion rating differed across groups in the explicit regulation condition [$F_{(2, 156)} = 54.1$, $P < 0.001$, $\eta_p^2 = 0.410$; patient < SD < control, all pairwise $P < 0.001$]. However, the emotion rating did not show a significant difference across groups in the baseline [$F_{(2, 156)} = 0.6$, $P = 0.544$, $\eta_p^2 = 0.008$] and implicit regulation conditions [$F_{(2, 156)} = 1.6$, $P = 0.205$, $\eta_p^2 = 0.020$]. Alternatively, we also examined the interaction by testing the condition effect in different groups (Fig. 2B; see Supplementary Materials).

Parietal LPP Amplitude

ANOVA tests showed significant main effects of group [$F_{(2, 156)} = 4.3$, $P = 0.015$, $\eta_p^2 = 0.052$; patient > control] and condition [$F_{(2, 312)} = 85.3$, $P < 0.001$, $\eta_p^2 = 0.353$; baseline > implicit/explicit] and significant interaction of condition × group [$F_{(4, 312)} = 13.6$, $P < 0.001$, $\eta_p^2 = 0.148$; Fig. 3A]. Simple effect analysis reveals that the LPP amplitudes differed across groups in the explicit regulation condition [$F_{(2, 156)} = 16.0$, $P < 0.001$, $\eta_p^2 = 0.170$; patient > SD/control, pairwise $P < 0.001$]. However, the LPP amplitudes did not show a significant difference across groups in the baseline [$F_{(2, 156)} = 1.5$, $P = 0.230$, $\eta_p^2 = 0.019$] and implicit regulation conditions [$F_{(2, 156)} = 0.1$, $P = 0.942$, $\eta_p^2 = 0.001$]. Alternatively, we also examined the interaction by testing the condition effect in different groups, which indicated that while the healthy group achieved the best emotion regulation effect by explicit reappraisal, the patients had an optimal regulatory effect by implicit reappraisal (Fig. 3B).

Frontal P3 Amplitude

ANOVA tests revealed significant main effect of condition [$F_{(2, 312)} = 19.0$, $P < 0.001$, $\eta_p^2 = 0.108$; explicit > baseline/implicit] and interaction of condition × group [$F_{(4, 312)} = 7.2$, $P < 0.001$, $\eta_p^2 = 0.085$; Fig. 4A]. Simple effect analysis revealed that the P3 amplitudes differed across groups in the

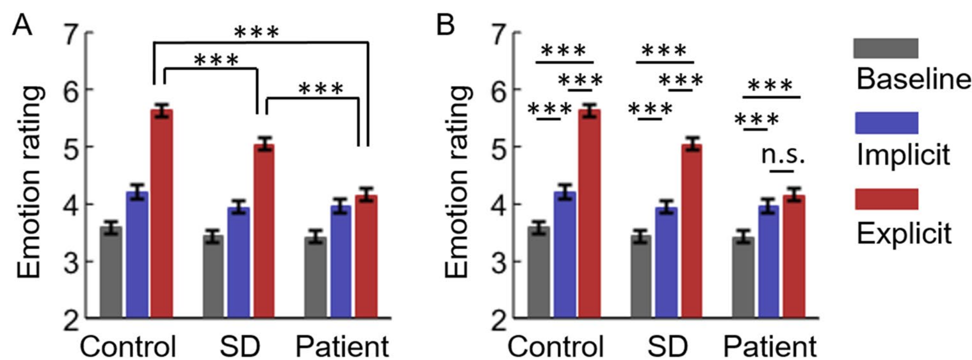

Fig. 2 Subjective emotion ratings. **A** Emotion ratings compared between groups. **B** Emotion ratings within each group. SD, subthreshold depression; implicit, implicit reappraisal; explicit, explicit reappraisal. Error bars, 2× SEM. ****P* <0.001; n.s., no significant difference, Repeated-measures ANOVA tests were applied to the subjective rating, and Greenhouse-Geisser correction for the ANOVA tests was used whenever appropriate (*n* = 159).

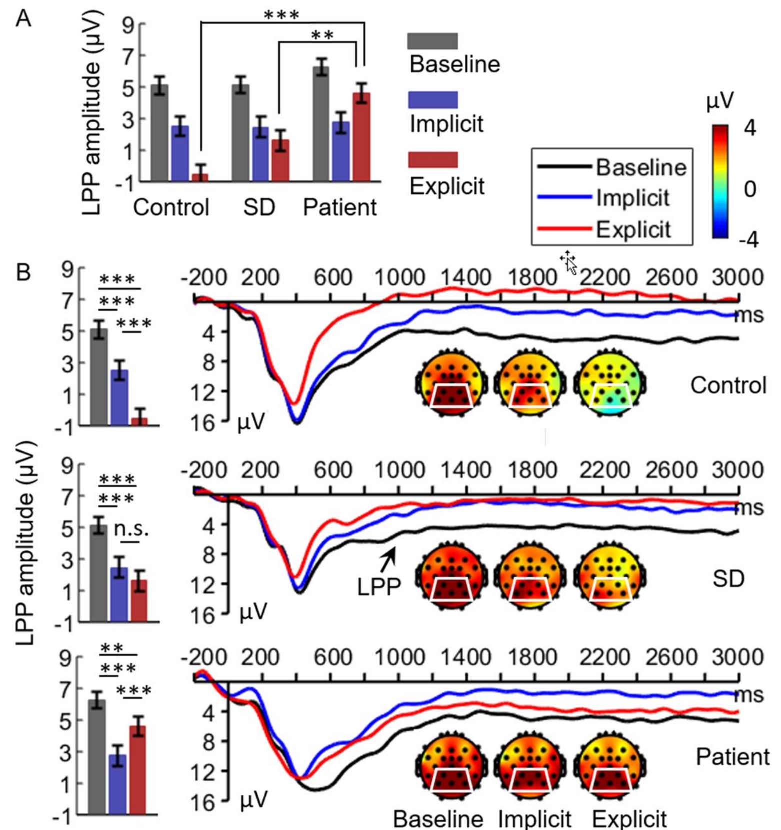

Fig. 3 The parietal late positive potential (LPP). **A** Amplitudes of the LPP compared between groups. **B** Waveforms, topographies, and amplitudes of the LPP within each group. ERP waveforms are averaged across electrodes Pz, P3, P4, CP1, and CP2 (white trapezoid). ERP topographies are averaged across a time window of 500–3000 ms after outcome onset. Error bars, 2× SEM. $**P<0.01$, $***P<0.001$; n.s., no significant difference. Repeated-measures ANOVA tests were applied to the parietal LPP, and Greenhouse-Geisser correction for the ANOVA tests was used whenever appropriate ($n = 159$).

explicit regulation condition [$F_{(2, 156)} = 4.8$, $P = 0.009$, $\eta_p^2 = 0.058$; patient < control/SD]. However, the P3 amplitudes did not show a significant difference across groups in the baseline [$F_{(2, 156)} = 0.3$, $P = 0.757$, $\eta_p^2 = 0.004$] and implicit regulation conditions [$F_{(2, 156)} = 0.0$, $P = 0.943$, $\eta_p^2 = 0.001$]. Alternatively, we also examined the interaction by testing the condition effect in different groups, which suggested that the explicit regulation-related enhancement of frontal P3 amplitudes in the control and SD groups was absent in the patients (Fig. 4B).

Correlations

Frontal P3 amplitudes were negatively correlated with parietal LPP amplitudes during explicit reappraisal ($r = -0.226$) but not under baseline or implicit conditions. While emotional ratings negatively predict LPP amplitudes under implicit and baseline conditions, they had limited or no predictive ability for the LPP amplitudes during explicit regulation in depressed individuals (Table 2). The emotion ratings in the explicit regulation condition were negatively correlated with BDI-II ($r = -0.565$) and STAI-T scores ($r = -0.392$), but positively correlated with ERQ-R ($r = 0.280$) and TCQ-R scores ($r = 0.294$). The LPP amplitudes in the explicit regulation condition were positively correlated with the BDI-II scores ($r = 0.248$). See Supplementary Material for details.

Discussion

Impaired emotion regulation plays a pivotal role in the development and maintenance of depressive disorders [1, 11]. To explore methods that may compensate for the emotion-regulatory deficits in depression, we compared the emotion regulation effects between explicit and implicit reappraisal in healthy, subclinical depression, and MDD populations. The results showed depressive patients had a better emotion regulation effect *via* implicit relative to explicit reappraisal, as shown by the LPP amplitudes in brain potentials, indicating the implicit form of reappraisal is more effective for depressive patients to achieve desirable emotion regulation.

Previous studies have shown that explicit reappraisal of negative events can effectively reduce emotion intensity [58, 71–73]. Consistent with these findings, our results demonstrated that, upon negative feedback, explicit reappraisal produced more positive emotion ratings and reduced LPP amplitudes compared to the baseline condition across the three groups. However, the utility of explicit reappraisal in regulating negative emotion showed a downward change depending on the severity of depression. This pattern was

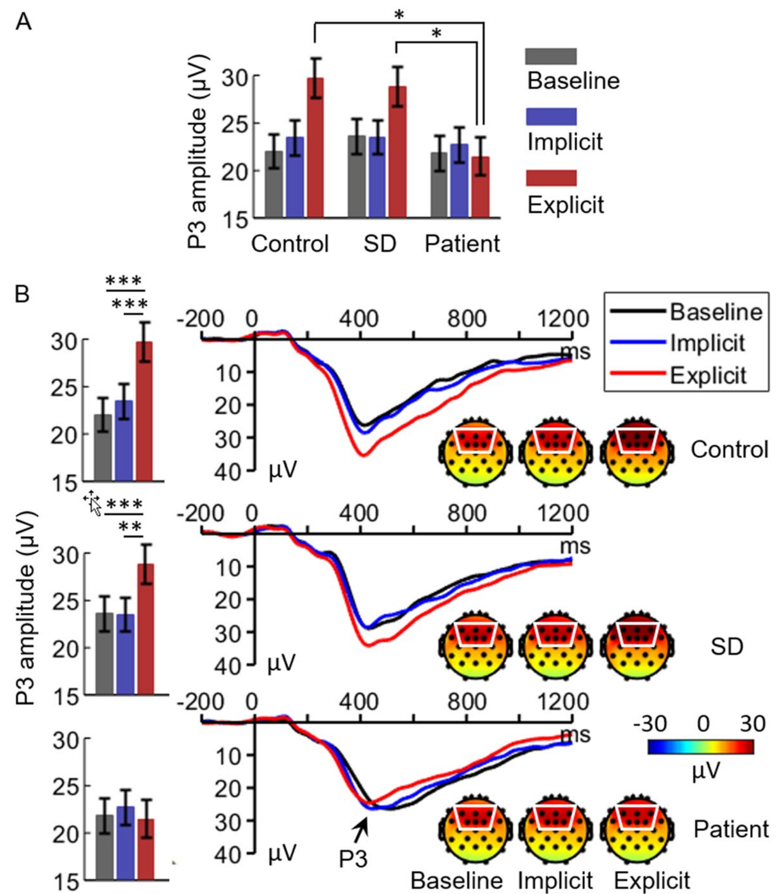

Fig. 4 The frontal P3. **A** Amplitudes of the P3, compared between groups. **B** Waveforms, topographies, and amplitudes of the P3 within each group. ERP waveforms are averaged across electrodes FCz, FC1, FC2, Fz, F3, and F4 (white trapezoid). ERP topographies are averaged across a time window of 300–600 ms after outcome onset. Error bars, 2× SEM. *P <0.05, **P <0.01, ***P <0.001. Repeated-measures ANOVA tests were applied to the frontal P3, and Greenhouse-Geisser correction for the ANOVA tests was used whenever appropriate (n = 159).

Table 2 Correlation statistics between LPP amplitudes and subjective ratings

Condition	Control (n = 54)			Subthreshold (n = 52)			Patient (n = 53)		
	r	P	P_{cor} [a]	r	P	P_{cor} [a]	r	P	P_{cor} [a]
Baseline	−0.501	<0.001	<0.001	−0.496	<0.001	0.001	−0.492	<0.001	<0.001
Implicit	−0.456	0.001	0.002	−0.523	<0.001	<0.001	−0.501	0.001	<0.001
Explicit	−0.358	0.008	0.024	−0.180	0.201		−0.104	0.459	

[a]Corrected using the Holm's stepwise method.

also evident in the correlations showing the higher the BDI scores, the larger the LPP amplitudes and more negative the emotion rating specific to explicit regulation. These results are in line with earlier findings that cognitive and behavioral correlates of depression do not change qualitatively but differ quantitatively along a continuum of mild, moderate, and severe depression [74, 75]. Also, these results are supported by prior reports that depressed patients have deficits in emotion regulation through the explicit use of regulatory strategies [1, 11, 15].

Many studies have established that explicit emotion regulation relies on a top-down cognitive control mechanism, which entails a substantial involvement of cognitive resources [23–25]. However, depressed patients are known for the depletion of cognitive resources by depressive symptoms and then for impaired cognitive functions [17–20, 76, 77]. In addition, several functional magnetic resonance imaging (fMRI) studies and meta-analyses have consistently shown that depressed individuals have reduced activation of cognitive-control-related brain regions, resulting in an enhanced amygdala response during explicit reappraisal [1, 2, 15, 16, 78]. Consistent with these findings, our analysis of frontal P3, a component considered to tap into the cognitive control process in emotion regulation [55, 56], showed larger amplitudes in explicit compared to the other two conditions in healthy control and subthreshold groups but not in MDD patients, which confirms the deficits of cognitive control in depression as reported by prior studies [17–22]. The role of the cognitive control deficit in the patients' reappraisal difficulty was further supported by our finding of a negative

correlation between frontal P3 and parietal LPP amplitudes specific to the explicit reappraisal condition.

Unlike explicit emotion regulation, we found a stable emotion-regulatory effect of implicit reappraisal in LPPs and emotion ratings across the healthy control, subclinical, and patient groups. Many studies have shown that implicit regulation of negative emotion is achieved with little involvement of cognitive control resources [29–31, 79]. Once primed, implicit emotion regulation occurs and functions automatically during the presentation of emotional events, without the need for effortful control [26]. Several fMRI studies have demonstrated that implicit emotion regulation effectively reduces amygdala activation without increased activity in the frontoparietal cognitive control regions [26, 79]. Consistent with these findings, in the current study we did not show any differences between implicit and baseline conditions in frontal P3 amplitudes. Little requirement of effortful control most likely explains our finding that implicit reappraisal significantly reduced subjective emotion and LPP amplitudes, unaffected by the symptoms of depression across the three groups.

It is worth noting that the optimal regulatory method varied significantly with the level of depression, in that explicit emotion regulation generated the largest regulatory effect in the controls but implicit emotion regulation produced the largest regulatory effect in the patients. One explanation is that, unlike depression, controls have intact cognitive control functions for explicit emotion regulation. Indeed, quite a few studies have shown that healthy people tend to use cognitive reappraisal preferentially for the regulation of negative emotions elicited by daily-life stimuli [54, 80]. By contrast, due to cognitive resource depletion, patients are unable to use explicit cognitive reappraisal to effectively regulate negative emotions [1, 76, 77]. However, implicit emotion regulation has the advantage that it does not require the online mobilization of cognitive resources to achieve the goal of emotion regulation [29–31]. More relevant to the current work, a recent study demonstrated that implicit priming of attention distraction is more efficient than explicit attention distraction in regulating frustration-induced emotion in depressed, but not healthy, individuals [34]. Consistent with these studies, our results revealed that implicit reappraisal is more effective for reducing negative emotion in depressed patients than explicit reappraisal as indicated by the LPP amplitudes.

It should be noted that the emotion-regulation effects were inconsistent between emotion ratings and LPP amplitudes in the subclinical and patient groups. Specifically, we found a lower negative emotion rating for explicit compared to implicit conditions, but the two conditions produced a similar emotion regulation effect in LPP amplitudes, in the subclinical group. Meanwhile, the patients showed a similar emotion rating during explicit and implicit regulation (both less negative than baseline), but they exhibited significantly smaller LPP amplitudes during implicit than explicit reappraisal. Participants received explicit instructions of reappraisal to reduce negative emotion upon negative feedback in the explicit but not the implicit condition. Therefore, emotion ratings in the explicit regulation condition may be susceptible to social desirability or self-anticipation that is absent during the implicit condition [42–44]. Consistent with this inference, the patient and subclinical groups showed significant correlations between LPP amplitudes and emotion ratings in the baseline and implicit conditions but not in the explicit condition (Table 2). Therefore, the electrophysiological index of LPP amplitudes can be considered a more reliable, objective indicator of emotion regulation effects than the emotion ratings.

Finally, it is notable that, in the current study we manipulated a dot counting task with negative feedback to induce negative emotions because this scenario simulated well real frustration in daily life [37] so as to enhance the ecological validity of this study. Unlike our manipulation, many previous studies assessed the effect of implicit emotion regulation using other stimulus types (e.g., affective pictures and film clips) to induce negative emotions such as anger and sadness in participants [39, 81]. Both these studies and the current one consistently demonstrated that various unpleasant feelings can be ameliorated by implicit emotion regulation.

To sum up, in this study we revealed that, compared with healthy subjects, depressed individuals have impaired emotion regulation through explicit reappraisal, and this impairment increases with the severity of depression. More importantly, we further revealed that the implicit form of emotion regulation is reliable and independent of depressive symptoms. This has important clinical implications for the cognitive intervention in depression through implicit emotion-regulation methods, considering the high rate of drop-out when a traditional, explicit form of cognitive-behavior therapy is used [82, 83]. However, these conclusions are primarily based on the measurement of LPP amplitudes evoked by immediate frustrating feedback. Also, we used single-session, short-term priming to establish implicit emotion regulation. Therefore, how to translate the current finding into a long-term, sustainable effect of depression intervention needs to be explored in future studies, probably by establishing multiple-session protocols.

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Conflict of interest Authors declare no conflicts of interest in this study.

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