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Neurosci. Bull.
https://doi.org/10.1007/s12264-023-01036-7

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ORIGINAL ARTICLE

Implicit, But Not Explicit, Emotion Regulation Relieves Unpleasant Neural Responses Evoked by High-Intensity Negative Images

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Received: 16 August 2022 / Accepted: 13 November 2022
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Abstract Evidence suggests that explicit reappraisal has limited regulatory effects on high-intensity emotions, mainly due to the depletion of cognitive resources occupied by the high-intensity emotional stimulus itself. The implicit form of reappraisal has proved to be resource-saving and therefore might be an ideal strategy to achieve the desired regulatory effect in high-intensity situations. In this study, we explored the regulatory effect of explicit and implicit reappraisal when participants encountered low- and high-intensity negative images. The subjective emotional rating indicated that both explicit and implicit reappraisal down-regulated negative experiences, irrespective of intensity. However, the amplitude of the parietal late positive potential (LPP; a neural index of experienced emotional intensity) showed that only implicit reappraisal had significant regulatory effects in the high-intensity context, though both explicit and implicit reappraisal successfully reduced the emotional neural responses elicited by low-intensity negative images. Meanwhile, implicit reappraisal led to a smaller frontal LPP amplitude (an index of cognitive cost) compared to explicit reappraisal, indicating that the implementation of implicit reappraisal consumes limited cognitive control resources. Furthermore, we found a prolonged effect of implicit emotion regulation introduced by training procedures. Taken together, these findings not only reveal that implicit reappraisal is suitable to relieve high-intensity negative experiences as well as neural responses, but also highlight the potential benefit of trained implicit regulation in clinical populations whose frontal control resources are limited.

Keywords Cognitive reappraisal · Implicit emotion regulation · Training · Emotional intensity · Late positive potential

Yueyao Zhang and Sijin Li contributed equally to this work.

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Introduction

Cognitive reappraisal is an adaptive and effective strategy of emotion regulation, which requires one to change his/her interpretation or evaluation of affective stimuli/scenarios so as to alter their emotional impacts according to the goal of emotion regulation [1, 2]. Studies have demonstrated that down-regulating negative emotions using reappraisal results in not only reductions in negative feelings [3, 4] but also decreased activation of the amygdala and insula, brain regions in which affective information is encoded and represented [5–7]. However, growing evidence suggests that both the usage preference and regulatory effect of reappraisal are largely reduced in affective scenarios with a high (but not low) emotional intensity [8–13]. For instance, Shafir *et al*. [9] examined the strategy preference of reappraisal and distraction in the pre-implementation stage and found that anticipation of high-intensity negative stimuli resulted in reluctant usage of the reappraisal strategy. Meanwhile, studies found that participants fail to down-regulate their emotional responses to highly intensive negative images *via* reappraisal strategies [8]. This phenomenon is caused

Published online: 06 March 2023

by insufficient cognitive control resources that are needed to support the implementation of reappraisal in the context of highly intense emotional stimuli [14, 15]. On the one hand, successful implementation of reappraisal places a high demand on cognitive control resources that are needed to support working memory, semantic representation, and the generation of new interpretations of affective scenarios [16, 17]. In line with this notion, neuroimaging evidence consistently shows extensive recruitment of the lateral prefrontal cortices for top-down cognitive control during reappraisal [18–20]. On the other hand, salient affective information such as highly stressful or threatening situations *per se* consumes a mass of cognitive resources, because evolution makes individuals allocate, automatically or voluntarily, more attention, evaluation, inhibition, and executive resources to dealing with high compared to low-intensity stimuli/events [21–23].

Longitudinal studies have shown that high-intensity negative events threaten both the physical and mental health of individuals, such as increased pain and disability, elevated risks of psychiatric disorders, and deteriorating family relationships [24, 25]. So how can individuals efficiently down-regulate the unpleasant feelings evoked by high-intensity negativity? Automatic, implicit emotion regulation might be an ideal solution. Implicit emotion regulation is an unconscious change of emotional quality, intensity, or duration without explicit instruction or deliberate control [26–28]. Many studies have revealed that implicit emotion regulation consumes very limited cognitive control resources [29–31]. For instance, Zhang *et al*. [32] found that implicit regulation decreases activity in the amygdala and insula, but does not increase activity in the frontoparietal control network. Similarly, electrophysiological evidence showed no alteration of the frontal positive slow component (an index of cognitive control) when participants down-regulated negative emotions implicitly [33]. Therefore, implicit emotion regulation might be suitable for high-intensity negative emotion due to its resource-saving characteristic.

To initiate and enhance the effect of implicit regulation, the word matching task and sentence unscrambling task are frequently used to prime the goal of emotion regulation [29, 34, 35]. In both tasks, participants are presented with a series of words, among which some are specifically designed to contain meanings of emotion regulation (e.g., reappraisal). In particular, participants are required to choose one from two words in the word matching task and match it to the target word related to an emotion-regulation meaning [33]. Similarly, participants are instructed to select appropriate items from several word jumbles to construct a grammatically correct sentence that involves a word with an emotion-regulation meaning [31]. These two priming methods have been proved to be effective for relieving unpleasant experiences elicited by follow-up negative cues/events and thus, show potential value in regulating emotions with high intensity [29, 30, 35]. However, the priming method has a relatively short-term effect (~1–3 min) [33, 35, 36]. Uncovering how to transfer this transient priming effect into a long-term benefit is urgent for applying implicit emotion regulation in practice.

In this study, we explored emotion regulation training, which is a safe and potential way to extend the beneficial effect observed in short-term (several minutes) lab studies into everyday therapeutic effects with a duration of several days, several months, or even several years [37–39]. For example, many researchers found that training in explicit emotion regulation improves daily emotional experiences [40], reduces symptoms of depression and anxiety [41, 42], and even promotes long-term marital quality [43]. Similarly, in a recent study, training in the working memory of emotional materials was used in individuals with high trait anxiety, and this resulted in reduced attentional bias to negative stimuli one-week post training [44]. So, is implicit emotion regulation training beneficial for reducing negative emotions for a long time? In this study, we explored this issue by repeatedly priming the reappraisal goal using word matching and sentence unscrambling tasks and testing the regulatory effect after 1 h of training.

To resolve the two issues described above, i.e., (1) the impact of emotional intensity on the regulatory effect of explicit and implicit reappraisal, and (2) the long-term benefit introduced by implicit training, this study was designed to have two within-subject factors: regulation type (baseline for control, training of implicit regulation, and explicit regulation guided by instructions) and emotional intensity (low/high). We collected self-reported emotion ratings and event-related potentials (ERPs) to assess the emotional response to high- and low-intensity affective images. While self-reported ratings have been widely used to measure emotional responses [45], they are likely to be biased toward participants' knowledge of the experimental goals (e.g., biased to the goal of explicit instructions of emotion regulation) [46, 47]. Thus, we added ERPs as objective indexes to monitor the emotional processing and responses of participants [48, 49]. Specifically, the parietal late positive potential (LPP) and frontal LPP were used as indicators. The parietal LPP reflects experienced emotional intensity [50, 51] and is usually considered a reliable index of the emotion regulation effect [52, 53]. Previous studies in our lab have demonstrated that the amplitude of the parietal LPP consistently declines while down-regulating negative emotions [54–56]. Besides the parietal LPP, the frontal LPP has been accepted as an index of cognitive effort [9, 57, 58]. Studies have shown that while explicit reappraisal enhances the amplitude of the frontal LPP [9, 58], this measure is not significantly enhanced during automatic, implicit reappraisal that is either initiated by implementation intention [57] or primed by the word matching task [36].

The hypothesis of this study is two-fold. We first hypothesized that although both implicit and explicit reappraisal can down-regulate low-intensity negative emotions, the effect of emotion regulation is only significant for the implicit method in the high-intensity negative context. Second, it is hypothesized that the well-known transient (several minutes) effect of emotion regulation induced by implicit priming can be transferred to a relatively long-term (>1 h) benefit induced by implicit training. Accordingly, the expectations for the dependent variables of this study are as follows. For the indexes of reappraisal outcome, we expected both the measures of self-reported emotional rating and the amplitude of parietal LPP would show the effect of emotion regulation compared to the baseline condition, i.e., emotion regulation results in less negative rating and a smaller parietal LPP. However, the effect of emotion regulation would be more significant in the training-induced implicit condition compared to the explicit reappraisal when high-intensity images (i.e., images with low valence and high arousal) are presented, though both methods are efficient for low-intensity scenarios. For the index of effort costs, we expected that the frontal LPP would show a lower amplitude in implicit than in explicit reappraisal irrespective of emotional intensity [29, 31–33].

Materials and Methods

Participants

Before the experiment, *a priori* power analysis was performed using G*power 3.1.7 [*F*-tests, analysis of variance (ANOVA): repeated measures, within-subject factors] with an effect size reported in our previous related study (η_p^2 = 0.253) [36]. According to the result of this power analysis, a total sample size of 8 participants would ensure 80% statistical power. However, 8 participants are a small sample size in present-day neuroscience studies. Thus, we finally decided to include 50 participants, which ensured a statistical power of >99%.

All 50 participants (mean age = 21.1 years, 28 men) were healthy and medication-free at the time of the experiment. They reported no history of neurological or psychiatric disorders and had normal or corrected-to-normal vision. All procedures performed in this study were in accordance with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The experimental protocol was approved by the Ethics Committee of Shenzhen University. Informed consent was signed by the participants before their engagement in the experiment. Behavioral or electroencephalogram (EEG) data were not available for three participants due to technical problems. As a result, the final sample consisted of 47 participants.

Experimental Materials

Materials for Training

We used 50 reappraisal-related and 50 emotion-regulation-unrelated sentences in the sentence unscrambling task [29, 31, 34]. Each reappraisal-related sentence contained a word with the meaning of cognitive reappraisal. For example, "他改变了对这件事的看法" (he changed his mind), "改变" (change) in this sentence is a reappraisal-related word. The emotion-regulation-unrelated sentences did not contain any words that were related to emotion regulation. For example, "树上结满了果实", which means "the trees are laden with fruit".

Besides the sentence unscrambling task, participants were also trained in the word match task. A total of 210 words were selected from one of our previous studies [33]. There were 70 reappraisal-related and 140 emotion-regulation-unrelated words. The reappraisal-related items conveyed semantic meanings related to cognitive reappraisal, e.g., "祸福相依", which means "fortune and misfortune are intertwined". The emotion-regulation-unrelated item did not convey any semantic meanings related to emotion regulation, e.g., "五光十色", which means "bright color and various patterns".

The emotional valence (1 = very unpleasant; 9 = very pleasant) and arousal (1 = very low; 9 = very high) of these words and sentences were rated by another 20 homogeneous participants. Independent samples *t*-tests showed that there were no significant differences between reappraisal-related and reappraisal-unrelated words [valence: $t_{(208)} = -0.2$, P = 0.805, 5.57 ± 0.06 *vs* 5.59 ± 0.06; arousal: $t_{(208)} = -1.2$, P = 0.243, 4.24 ± 0.06 *vs* 4.34 ± 0.06], or between reappraisal-related and reappraisal-unrelated sentences [valence: $t_{(98)}$ = 1.4, P = 0.166, 5.42 ± 0.05 *vs* 5.32 ± 0.05; arousal: $t_{(98)}$ = −0.9, P = 0.346, 4.17 ± 0.07 *vs* 4.25 ± 0.04].

Materials for Testing

One hundred and eighty negative pictures were collected from the International Affective Picture System [59] and the Chinese Affective Picture System [60]. There were 90 low- and 90 high-intensity pictures. The valence (1 = very unpleasant; 9 = highly pleasant) and arousal (1 = very low; 9 = very high) of these 180 pictures were rated by another 30 homogeneous college students. Independent samples *t*-tests showed that low- and high-intensity pictures were significantly different in both the valence [$t_{(178)} = -8.3$, P <0.001; low- *vs* high-intensity = 3.88 ± 0.07 *vs* 2.99 ± 0.08] and arousal ratings [$t_{(178)} = 7.6$, $P < 0.001$; 4.45 ± 0.10 *vs* 5.68 ± 0.13], which suggested that the two sets of images indeed covered low- and high-intensity negative emotions.

The 180 pictures were assigned randomly into the three blocks (baseline, implicit, and explicit), with 30 low- and 30 high-intensity images in each block. These images depicted various negative contents such as fear, sadness, disgust, and threat. The categories of negative emotions were matched among the three blocks. ANOVA showed no significant difference in valence [$F_{(2, 177)} = 1.5$, $P = 0.216$; 3.52 ± 0.11 *vs* 3.51 ± 0.11 *vs* 3.28 ± 0.10] or arousal [$F_{(2, 177)} = 1.0$, $P = 0.366$; 5.01 ± 0.16 *vs* 4.94 ± 0.17 *vs* 5.25 ± 0.15] of the images across the three blocks.

During the experiment, the images were presented in the center of an LCD screen at a viewing angle of 3.0° × 3.5°.

Experimental Procedure

The experiment was divided into three blocks corresponding to the three regulation types. The three blocks were performed by each participant at the same time (i.e., all during 09:00–12:00 or 15:00–18:00) on three consecutive days. We fixed the order of blocks (baseline, implicit, and explicit) to ensure that (1) neither the baseline nor the implicit condition was impacted by the explicit instructions of emotion regulation in the explicit condition; (2) the baseline was not impacted by the training effect of implicit emotion regulation in the implicit condition. The experimental procedure is shown in Fig. 1A.

In both the baseline and implicit training conditions, participants were required to complete a 30-min training program consisting of word matching and sentence unscrambling tasks, followed by exposure to negative images after a rest period of 1 h (Fig. 1A). During training, participants were instructed to choose a word from two options so as to match it to a given target word based on the semantic meanings in the word matching task. Participants were also required in the sentence unscrambling task to select four words from five-word jumbles and reconstruct a sentence that was grammatically correct and semantically appropriate. The two training tasks were alternatively conducted until the 30-min training duration was reached. In the implicit training condition, the target word and one of the option words had reappraisal-related meanings in the word matching task; meanwhile, one word per sentence had a reappraisal-related meaning in the sentence unscrambling task. In contrast, none of the words had meanings of emotion regulation in the baseline condition. In the explicit block, participants were instructed explicitly to down-regulate the emotions *via* reappraisal strategy: "please re-interpret the content in the image from a less negative perspective. For example, you could think the unpleasant situation will soon be improved or some help is on the way".

In all three blocks, participants were tested for emotional responses to negative images while EEG data were recorded at this time. There were 30 low- and 30 high-intensity negative images in each block. Each image was presented for 5 s, during which participants were required to pay close

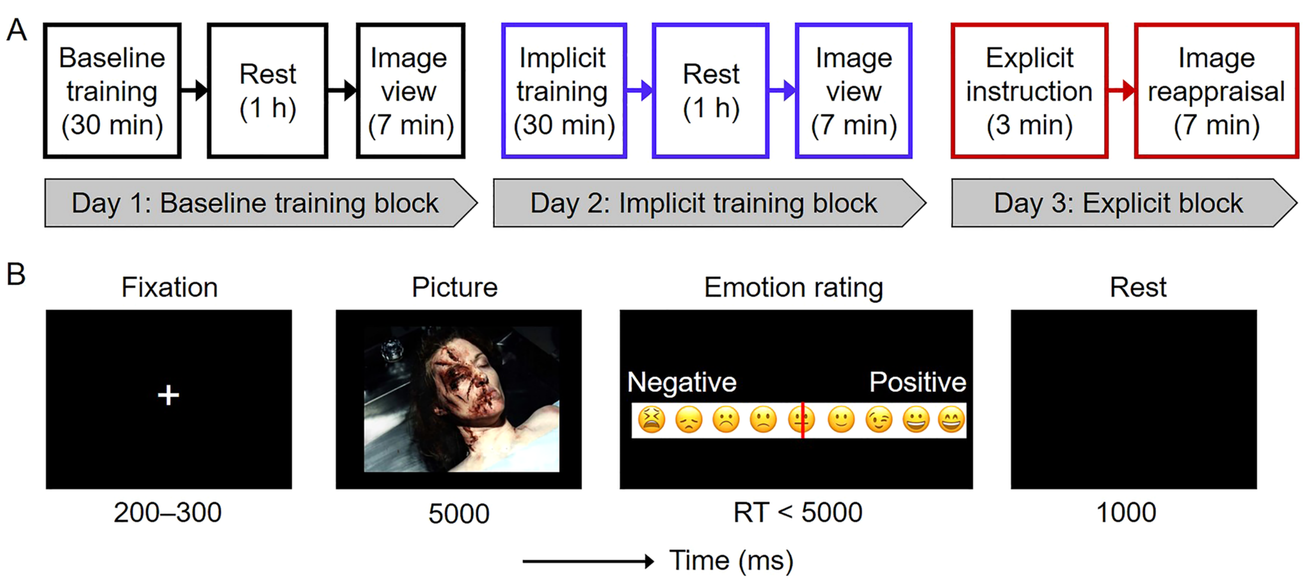

Fig. 1 Illustration of experimental procedures. **A** Sequence of the tasks. **B** Stimulus presentation in one trial of the image view or reappraisal. Emotion rating was required every 6 trials, during which participants reported their emotional feelings using the mouse on a continuous valence axis. RT, response time.

attention to the image (during baseline and implicit blocks) or reappraise the negative content (during the explicit block) (Fig. 1B). After viewing or reappraisal, emotion rating was required in every 6 trials and participants reported their emotional feelings by clicking the mouse on a continuous axis (from 0 to 1; 0 represented the most negative and 1 represented the most positive feelings) within 5 s. There were 10 samples of emotion ratings per block (5 followed low- and 5 followed high-intensity pictures).

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 online recorded referentially against the left mastoid and off-line re-referenced to the average of the left and right mastoids. EEG data were collected with electrode impedances kept below 10 kΩ. The recorded data were then offline filtered (half-amplitude cutoff: 0.01–20 Hz) and segmented beginning 200 ms prior to picture presentation and lasting until pictures disappeared (duration = 5000 ms). Epochs were baseline-corrected with respect to the mean voltage over the 200 ms preceding picture presentation, followed by averaging in each condition.

In this study, we focused on the LPP components at the frontal and parietal regions. The frontal LPP was measured as the average amplitude across the electrode sites at and around FCz (FC1, FC2, Fz, F3, and F4). The *a priori* time window for the frontal LPP amplitude (700–1100 ms after picture onset) was chosen according to previous literature [9, 57].

The parietal LPP was measured as the average amplitude across the electrode sites at and around Pz (P3, P4, Pz, CP1, and CP2). The *a priori* time window for the parietal LPP amplitude was chosen according to previous literature [53, 56, 61]. This window began at the end of the typical P3 (1000 ms) and lasted until the end of the emotional regulation period (5000 ms after picture onset).

Statistics

Statistical analysis was performed using SPSS Statistics 22.0 (IBM, Somers, USA). Descriptive data are presented as the mean ± SEM. The significance level was set at 0.05. Repeated-measures ANOVA tests were performed on subjective ratings of feelings and the LPP amplitudes, with the regulation type (baseline/implicit/explicit) and emotional intensity (low/high) as two within-subject factors. The Greenhouse-Geisser correction for the ANOVA tests was used whenever appropriate. Multiple comparisons were corrected using the Bonferroni method. A two-tailed Pearson's correlation was performed between the subjective ratings and the parietal LPP amplitudes. Multiple comparisons were corrected using the false discovery rate method.

Data and Code Availability

The data and code of this study would be available upon reasonable request. More information can be obtained from the corresponding author, Dr. Dandan Zhang.

Results

Self-reported Emotion Rating

The main effect of regulation type was significant [$F_{(2, 92)} = 101.7$, $P < 0.001$, $\eta_p^2 = 0.689$]: Emotion ratings were the least negative in explicit regulation (0.476 ± 0.014) and were of a lesser extent, in implicit regulation (0.316 ± 0.012) compared to baseline (0.232 ± 0.013; pairwise $P < 0.001$). The main effect of emotional intensity was significant [$F_{(1, 46)} = 43.0$, $P < 0.001$, $\eta_p^2 = 0.483$]: participants reported more negative emotions in response to the pictures with high (0.312 ± 0.009), compared with low (0.370 ± 0.009), emotional intensity.

The interaction of regulation type × emotional intensity was also significant [$F_{(2, 92)} = 6.4$, $P = 0.003$, $\eta_p^2 = 0.122$; Fig. 2A]. Simple effect analysis revealed that although the effect of regulation type achieved a significant level in both emotional intensity conditions, the effect size was larger in the low-intensity condition [low: $F_{(2, 45)} = 90.0$, $P < 0.001$, $\eta_p^2 = 0.800$; high: $F_{(2, 45)} = 52.6$, $P < 0.001$, $\eta_p^2 = 0.701$]. Specifically, while the three regulation types resulted in distinct emotion ratings in the low-intensity condition (baseline 0.245 ± 0.014 < implicit 0.353 ± 0.013 < explicit 0.512 ± 0.015; pairwise $P < 0.001$), the difference between regulation types was slightly reduced in the high-intensity condition (baseline 0.218 ± 0.015 < implicit 0.279 ± 0.013 < explicit 0.440 ± 0.016; pairwise $P \leq 0.001$).

Parietal LPP Amplitude

The main effect of regulation type was significant [$F_{(2, 92)} = 9.7$, $P < 0.001$, $\eta_p^2 = 0.174$]: the LPP amplitude in the implicit (3.21 ± 0.49 μV, $P = 0.001$) and explicit (4.22 ± 0.59 μV, $P = 0.033$) regulation conditions was smaller than that in the baseline (5.58 ± 0.71 μV), while no significant difference was found between the former two conditions ($P = 0.134$). The main effect of emotional intensity was also significant [$F_{(1, 46)} = 47.0$, $P < 0.001$, $\eta_p^2 = 0.505$]: the LPP amplitude was larger in response to affective pictures with high (5.55 ± 0.56 μV) compared to low intensity (3.12 ± 0.53 μV).

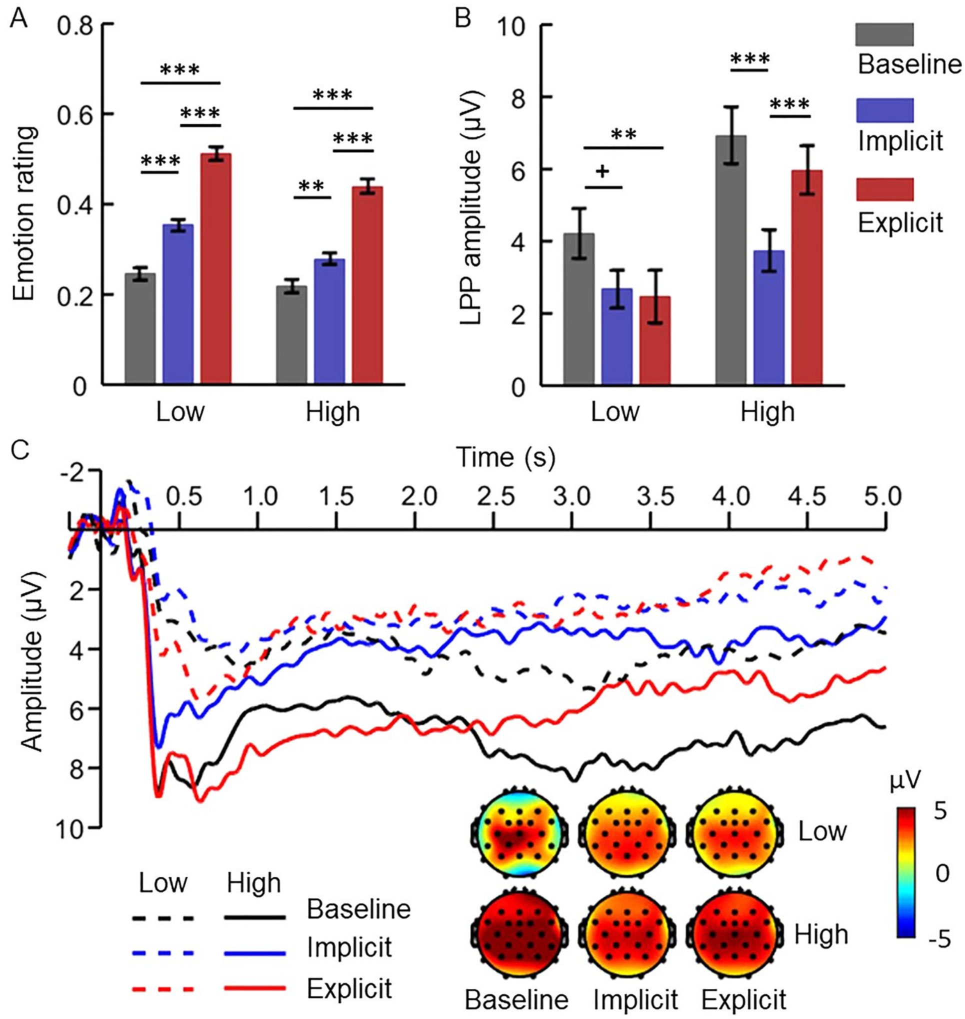

Fig. 2 Emotional rating and the parietal late positive potential (LPP). **A** Emotion ratings. **B** Amplitudes of the parietal LPP. For **A** and **B**: $n = 47$. Repeated-measures ANOVA tests with Greenhouse-Geisser correction. Multiple comparisons were corrected using the Bonferroni method. Error bars indicate 2× SEM. ***P <0.001; **P <0.01; $^{+}0.05 < P < 0.100$. **C** Waveforms and topographies of the parietal LPP. ERP waveforms were averaged across electrodes of Pz, P3, P4, CP1, and CP2. ERP topographies were averaged across a time window of 1–5 s after picture onset.

Notably, the interaction of regulation type × emotional intensity was significant [$F_{(2,\,92)} = 4.8$, $P = 0.013$, $\eta_p^2 = 0.094$; Fig. 2B, C]. Simple effect analysis revealed that although the effect of regulation type achieved a significant level in both emotional intensity conditions, the patterns of this effect were different between the low [$F_{(2,\,45)} = 6.8$, $P = 0.003$, $\eta_p^2 = 0.233$] and high intensity conditions [$F_{(2,\,45)} = 11.8$, P <0.001, $\eta_p^2 = 0.344$]. For affective pictures with low intensity, the LPP amplitude in implicit (2.67 ± 0.52 μV, $P = 0.056$; marginally significant) and explicit (2.47 ± 0.73 μV, $P = 0.009$) regulation conditions was smaller than that at baseline (4.22 ± 0.69 μV), while no significant difference was found between the former two conditions ($P = 1.000$). However, for affective pictures with high intensity, only the LPP amplitude in the implicit regulation condition (3.74 ± 0.58 μV, pairwise P <0.001) was significantly reduced, compared with that in the baseline (6.94 ± 0.79 μV) and explicit regulation conditions (5.98 ± 0.67 μV).

Correlations Between Parietal LPP Amplitudes and Emotion Ratings

Here we analyzed the correlations between the parietal LPP amplitudes and the ratings of emotions in the 3 × 2 conditions, separately. Results revealed that the two measures negatively correlated in baseline and implicit regulation conditions, and these correlations remained significant after correcting for multiple tests (Table 1).

An online computing software (Lee IA & Preacher KJ. October, 2013. Calculation for the test of the difference between two dependent correlations with no variable in common. Available from https://quantpsy.org) was used to compare the r values between regulation types in low- and high-intensity conditions separately. First, each r value was converted into a z-score, followed by a transfer to an asymptotic covariance. Then an asymptotic z-test was used to compare the asymptotic covariance. Results showed that the correlation coefficient during explicit regulation was smaller than that during implicit regulation (low intensity:

Table 1 Correlations between the parietal LPP amplitudes and emotion ratings

Regulation type	Low intensity			High intensity		
	r	P	P_{cor} [a]	r	P	P_{cor} [a]
Baseline	−0.350	0.016	0.032	−0.337	0.021	0.032
Implicit	−0.470	0.001	0.006	−0.449	0.002	0.006
Explicit	−0.106	0.476	NS	0.002	0.988	NS

[a]Corrected using the false discovery rate method. NS, not significant.

$z = 1.94$, $P = 0.052$, marginally significant; high intensity: $z = 2.27$, $P = 0.024$). Meanwhile, there was a trend that the correlation coefficient during explicit regulation was smaller than that during baseline (low intensity: $z = 1.23$, $P = 0.220$; high intensity: $z = 1.59$, $P = 0.111$). These results reveal that while emotional rating could predict LPP amplitudes in implicit and baseline conditions (the more positive emotion ratings, the smaller LPP amplitudes), it had limited or no predictive ability for the LPP amplitude during explicit emotion regulation due to biased subjective reporting.

Frontal LPP Amplitude

The main effect of regulation type was significant [$F_{(2, 92)}$ = 33.4, P <0.001, η_p^2 = 0.420]: the LPP amplitude in the explicit (5.55 ± 0.97 μV, pairwise P <0.001) was much larger than that in the baseline (−0.17 ± 0.70 μV) and implicit regulation conditions (1.52 ± 0.98 μV), while no significant difference was found between the latter two conditions (P = 0.083). The main effect of emotional intensity was also significant [$F_{(1, 46)}$ = 62.8, P <0.001, η_p^2 = 0.577]: the LPP amplitude was larger in response to affective pictures with high (4.57 ± 0.88 μV) compared to low intensity (0.03 ± 0.80 μV).

Furthermore, the interaction of regulation type × emotional intensity was significant [$F_{(2, 92)}$ = 4.3, P = 0.019, η_p^2 = 0.085; Fig. 3]. Simple effect analysis revealed that, although the effect of regulation type achieved a significant level in both emotional intensity conditions, the effect size was larger in the high-intensity condition [low: $F_{(2, 45)}$ = 20.2, P <0.001, η_p^2 = 0.473; high: $F_{(2, 45)}$ = 24.7, P <0.001, η_p^2 = 0.523]. Specifically, for affective pictures with high intensity, the LPP amplitude in explicit (8.41 ± 1.07 μV, pairwise P <0.001) was much larger than that in the baseline (1.47 ± 0.86 μV) and implicit regulation conditions (3.83 ± 1.14), and the LPP amplitude in implicit regulation was larger than that in baseline (P = 0.032). For affective pictures with low intensity, while the LPP amplitude in explicit (2.70 ± 0.99 μV, pairwise P <0.001) was also much larger than that in the baseline (−1.81 ± 0.71 μV) and implicit regulation conditions (−0.78 ± 0.99 μV), no significant difference was found between the latter two conditions (P = 0.554). Another direction of simple effect analysis showed

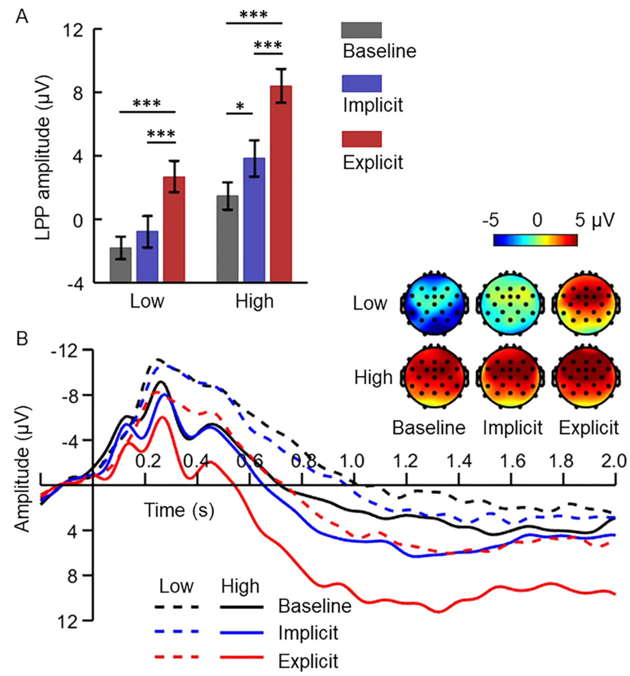

Fig. 3 The frontal late positive potential (LPP). **A** Amplitudes of the frontal LPP. Sample size 47. Repeated-measures ANOVA tests with Greenhouse-Geisser correction. Multiple comparisons were corrected using the Bonferroni method. Error bars indicate 2× SEM. ****P* <0.001; **P* <0.05. **B** Waveforms and topographies of the frontal LPP. ERP waveforms were averaged across electrodes of FCz, FC1, FC2, Fz, F3, and F4. ERP topographies were averaged across a time window of 700–1100 ms after picture onset.

that the effect of high *versus* low intensity was the largest in the explicit regulation condition [$F_{(1, 46)}$ = 67.2, P <0.001, η_p^2 = 0.594], followed by the implicit regulation condition [$F_{(1, 46)}$ = 31.0, P <0.001, η_p^2 = 0.403]; the effect was the smallest in the baseline [$F_{(1, 46)}$ = 21.3, P <0.001, η_p^2 = 0.316].

Discussion

Using subjective ratings and objective ERP measurements, we explored the effect of emotion regulation *via* explicit and implicit reappraisal. There are two main findings. First, both explicit and implicit regulation methods relieved low-intensity negative emotions, reflected by both the decreased negative rating and reduced parietal LPP amplitude. However, in the high-intensity negative context, although the two methods were both effective in reducing the subjective rating, only the implicit (but not the explicit) method showed a significant regulation effect in the parietal LPP. Second, the alleviation of negative emotions induced by implicit training was successful, and the effect of half-an-hour training persisted for at least 1 h.

We found stronger emotional responses (i.e., higher self-reported negativity and larger parietal LPP amplitudes) in high- compared to low-intensity negative contexts, which indicated the successful manipulation of emotional intensity in this study. Second, we found that both explicit and implicit reappraisal resulted in reduced negative experiences, as compared to the baseline condition. Thus, the two manipulated factors proved to be effective in this study.

The core finding was the two-way interaction between regulation type and emotional intensity. In the low-intensity context, we found that both explicit and implicit reappraisal reduced the unpleasant experiences induced by affective images, reflected by the decreased negative rating and reduced parietal LPP amplitudes, compared to the baseline condition. This finding is paralleled in the broad literature showing that low-to-moderate unpleasant feelings can be ameliorated by emotion regulation, especially the explicit methods [2–4]. In the high-intensity context, we found that implicit regulation training showed a robust regulation effect, reflected by both subjective and objective indicators of emotional responses. This result is consistent with our hypothesis and goes beyond our two previous studies focusing on implicit regulation [31, 33]: we now demonstrated that implicit reappraisal diminished negative experiences in both low- and high-intensity negative contexts. In contrast to the implicit regulation, the regulatory outcome in the explicit reappraisal condition differed between subjective and objective measures in the high-intensity context. In particular, while explicit reappraisal resulted in reduced negative self-reports, this regulation method did not decrease the amplitude of the parietal LPP, which is considered a reliable, neural index of the emotion regulation effect [51, 52]. When interpreting this inconsistent finding, we prefer to give more weight to the ERP index rather than the subjective rating, since self-reported measures are likely to be biased towards experimenters' expectations and/or experimental goals in the condition that the instruction of emotion regulation is explicitly given by experimenters [46, 47]. Similar expectation phenomena caused by explicit instruction have been reported in clinical practice, e.g., explicit instructions or suggestions were found to improve subjective experiences of emotion and pain even in the absence of real treatment [62, 63]. Intriguingly, our correlation results between self-reported rating and LPP amplitude supported this opinion: while the two measures showed significant correlation in both the implicit reappraisal and baseline conditions, they did not correlate with each other in the explicit condition. Again, this result may be due to the bias of subjective rating, which is caused by the explicit instruction to down-regulate negative feelings. Thus, according to the amplitude of parietal LPP, the current result indicated that explicit reappraisal has a very limited effect on down-regulating high-intensity negativity. In line with this finding, previous research has also found the ineffectiveness of explicit reappraisal in high-intensity situations, e.g., serious physical pain elicited by cold pressure [23] or intense stress elicited by impromptu public speaking [64].

In regard to cognitive cost, the frontal LPP showed enhanced amplitudes in high- compared to low-intensity negative situations, as well as enhanced amplitudes in explicit reappraisal compared to implicit reappraisal and baseline. This finding indicated that both explicit reappraisal and high-intensity scenarios cost a large amount of control resources located in the frontal cortices. The result paralleled previous neuroimaging findings suggesting elevated neural activation in the lateral prefrontal cortices during deliberate reappraisal [18, 20] but not during implicit emotion regulation [32, 33]. We also found a two-way interaction showing that the high-intensity negative images evoked the largest frontal LPP amplitude during explicit reappraisal among the 2×3 conditions. This result could be interpreted as that both high-intensity stimuli [23, 64] and intentional reappraisal implementation [16, 17, 20] require a large amount of frontal control resources, resulting in significantly enhanced frontal LPP. The most important indication revealed by the frontal LPP is that while explicit reappraisal works at the cost of frontal control resources, the implementation of implicit regulation needs much less control effort and is thus very suitable for emotion regulation in high-intensity situations.

Another contribution of this study was that we found that the effect of implicit emotion regulation could be introduced by a training procedure and was sustained for a relatively long time, which was much more lasting than the effect introduced by primed implicit regulation (several minutes). This finding highlights the potential benefit of trained implicit regulation in clinical applications. Most of the previous studies on implicit emotion regulation examined the emotional benefits caused by the priming method [65]. For instance, Wyczesany *et al.* [35] instructed participants to unscramble several sentences containing meanings of emotion regulation and then to view affective images within 1 min after the sentence unscrambling task. In the present study, we explored the prolonged effect of implicit regulation training *via* a repeated priming method. The emotional benefits caused by implicit, compared to the explicit, reappraisal in the high-intensity condition suggest that implicit training might be a suitable intervention in helping to improve emotional experiences in patients and old people whose frontal control resources are limited. For instance, a recent study in our lab revealed that explicit reappraisal capabilities are impaired in patients with major depressive disorder, whereas their implicit emotion regulation is intact and can reduce negative experiences effectively [36]. Future studies are recommended to test whether implicit training could benefit clinical populations in daily life. In addition, future research could also examine whether other valuable strategies (such as attention deployment) can be trained using implicit methods [66]. Further, implicit training benefits could be maximized by combining multi-sessions of training and longitudinal monitoring procedures.

One limitation of the study is that we fixed the order of the conditions (baseline, then implicit, and then explicit) to avoid the potential influence of explicit instruction on the baseline and implicit tasks. The quandary of this operation is to result in some habituation or fatigue effects and thus might reduce the credibility of the results. However, two arguments largely exclude this potential confusion. First, there was enough rest time between conditions (one day) during the experiment so it was unlikely to produce after-effects across conditions. Second, it has been demonstrated in our previous studies using counterbalanced order of conditions that the fixed order does not result in significant habituation or fatigue effects [36].

In summary, we investigated the impact of emotional intensity on the regulation effects of explicit and implicit reappraisal. We found that while explicit reappraisal was ineffective in reducing neural responses to high-intensity negative stimuli due to cognitive resource depletion, implicit regulation training consumed minimal frontal control resources and showed a robust regulation effect on both mild and intense negative emotions. These findings have useful implications for the application of implicit emotion regulation in clinical interventions to help patients with limited frontal control resources to improve their mood.

Acknowledgments This work was supported by the National Natural Science Foundation of China (32271102, 31970980, and 31920103009), the Major Project of the National Social Science Foundation (20&ZD153), the Shenzhen-Hong Kong Institute of Brain Science (2022SHIBS0003), and the Guangdong Key Project (2018B030335001).

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

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