Sustained Regulatory Effects of Implementation Intention-Based Cognitive Reappraisal on Negative Emotion: Longitudinal EEG Evidence

Authors: Li Yaqin, Dai Jiajia, Gao Wei, Yuan Jiajin, Yuan Jiajin

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Abstract

Implementation Intention-based Reappraisal (IIR), as a novel automatic emotion regulation strategy that combines implementation intentions (i.e., if-then plans) with adaptive cognitive reappraisal, can regulate negative emotions without increasing cognitive load, and this regulatory effect can generalize from the set context (If context) to non-set contexts. However, previous studies have not examined whether the generalization effect of IIR is sustainable. To address this issue, the present study employed EEG technology combined with a picture viewing task, using participants' self-reported valence, arousal, and late positive potential (LPP) as indicators to longitudinally investigate the emotion regulation effects of IIR on participants' immediate and one-week-later emotional responses. The results showed that from Day 0 to Day 7, compared with the control group, the IIR group exhibited continuously reduced emotional experience and arousal levels in response to set negative contexts (bloody images); moreover, this regulatory effect also stably appeared in arousal ratings for non-set contexts (non-bloody images). Additionally, on Day 0, Day 3, and Day 7, the IIR group showed smaller centroparietal LPP (400–1500 ms) amplitudes and frontal LPP (400–1100 ms) amplitudes compared with the control group; and there was a significant positive correlation between centroparietal LPP amplitude and arousal. These results demonstrate that IIR can not only regulate negative emotions over the long term and produce generalization effects, but also that its generalization effects exhibit certain sustainability. This study provides empirical support for the effectiveness and stability of IIR in the domain of emotion regulation.

Full Text

Sustainable Regulation Effects of Implementation Intention-Based Reappraisal on Negative Emotions: Longitudinal EEG Evidence

LI Yaqin[1,2], DAI Jiajia[1], GAO Wei[1], YUAN Jiajin[1,2] (1 Institute for Brain and Psychological Sciences, Sichuan Normal University; 2 Sichuan Key Laboratory of Psychology and Behavior of Discipline Inspection and Supervision (Sichuan Normal University), Chengdu 610066, China)

Abstract

Implementation Intention-Based Reappraisal (IIR) is a novel automatic emotion regulation strategy that combines implementation intentions (if-then plans) with adaptive cognitive reappraisal to regulate negative emotions without increasing cognitive load. Moreover, the regulation effect can generalize from specified situations (if situations) to unspecified situations. However, previous studies have not focused on whether the generalization effect of IIR is sustainable. To address this gap, this study utilized EEG technology in combination with a picture-viewing task to longitudinally investigate the emotion regulation effects of IIR in the present and over the following week, using participants'self-reported valence, arousal, and late positive potential (LPP) as indicators. Specifically, 51 valid participants were randomly assigned to the IIR group (25 individuals) and the control group (26 individuals). The two groups performed a picture-viewing task and all participants' valence and arousal for picture stimuli were simultaneously recorded at both the IIR acquisition phase (Day 0) and the post-IIR acquisition phase (Day 1, Day 3, Day 5, and Day 7), and their EEG activities for picture stimuli were recorded on Day 0, Day 3, Day 7. After data reduction and preprocessing, behavioral analysis included 49 participants (24 in the IIR group, 25 in the control group), and EEG analysis involved 44 participants (22 in each group).

Subjective self-reported results revealed that, compared to the control group, the IIR group sustainably decreased valence and arousal ratings for bloody pictures (specified situations) from Day 0 to Day 7. Furthermore, the diminishing effect of IIR on arousal also consistently appeared in unspecified situations (non-bloody pictures), suggesting that the generalization effect of IIR was somewhat persistent. The event-related potential (ERP) results showed that, compared to the control group, the IIR group had smaller amplitudes of centro-parietal LPP (in the time window of 400 ~ 1500 ms) and frontal LPP (in the time window of 400 ~ 1100 ms) on Day 0, Day 3, and Day 7, suggesting that the sustainable effect of IIR was stable on LPP indicators. Additionally, there was a significant positive correlation between centro-parietal LPP (in the time window of 400 ~ 2500 ms) amplitude and arousal. Together, these findings suggest that IIR exhibits sustainable regulation and generalization effects on negative emotions.

In conclusion, IIR could sustainably regulate negative emotions and produce generalization effects as evidenced by both behavioral and ERP indicators. This study provides additional evidence supporting the stability and effectiveness of IIR in emotion regulation. In addition, these findings contribute to advancing the theory of automatic emotion regulation. Specifically, the present study not only supports the auto-motive model of nonconscious goal pursuit and the temporal processing model of controlled-automatic emotion regulation, but also extends these theories by demonstrating the stability and generalization of IIR' s effects on emotion regulation.

Moreover, this study has certain clinical implications for interventions targeting emotional disorders. For example, IIR may be an effective approach for treating co-morbid symptoms of anxiety and depressive disorders.

Keywords: emotion regulation, implementation intention-based reappraisal, sustainable effect, generalization effect, late positive potential

Introduction

Automatic emotion regulation (AER) refers to the process by which individuals regulate emotions automatically or unconsciously under the drive of implicit or explicit goals (Mauss et al., 2007; 陈圣栋, 2020). The automatic model of unconscious goal pursuit posits that the mental representations corresponding to explicit or implicit goals (including emotion regulation goals) can automatically establish connections with other representations and function without conscious involvement when individuals consistently pursue the same goal (e.g., calmness) in a particular situation (e.g., fearful scenes) (Bargh, 1990; Bargh & Williams, 2007). Once the situation representation is activated, the connected goal representation is also automatically activated and takes effect, providing a theoretical foundation for automatic emotion regulation that has received empirical support (e.g., Bargh et al., 2001; Hassin et al., 2009).

In research on automatic emotion regulation, implementation intention paradigms, word-matching tasks, and sentence unscrambling tasks are commonly used to elicit automatic emotion regulation. The implementation intention paradigm forms an automatic "situation-response" association through "if-then" plans, thereby triggering automatic emotion regulation (Gallo et al., 2009), whereas word-matching or sentence unscrambling tasks elicit automatic emotion regulation through words or sentences with emotion or emotion regulation-related meanings (Mauss et al., 2007; Yang et al., 2015). Compared to intentional emotion regulation, the advantage of automatic emotion regulation lies in achieving emotion regulation goals without consuming or with minimal consumption of cognitive resources (Ding et al., 2015; Yang et al., 2015; 高伟等, 2018). For instance, Yang et al. (2015) used a word-pairing task to prime automatic emotion regulation and found that it could reduce negative emotional experience without consuming additional cognitive resources. Similarly, Ding et al. (2015) employed a sentence unscrambling task to prime automatic emotion regulation and discovered that it not only reduced physiological responses triggered by negative emotions but also better maintained emotional stability.

Furthermore, the combination of implementation intentions with cognitive reappraisal strategies (changing one' s interpretation or evaluation of emotional stimuli; Buhle et al., 2014) has given rise to a new form of automatic emotion regulation strategy: Implementation Intention-Based Reappraisal (IIR). This strategy primarily involves individuals forming an emotion regulation goal (e.g., "I will not feel disgusted") through practice and establishing an implementation intention-based cognitive reappraisal (e.g., "If I see blood, then I will view it from a doctor' s perspective"). After mastery, individuals can unconsciously use this strategy to regulate emotions without any emotion regulation-related instructions. Previous research has shown that implementation intentions help individuals achieve goals (Gollwitzer & Brandstätter, 1997; Webb et al., 2010) and are more effective than goal intentions in promoting emotion regulation, making them an effective way to elicit automatic emotion regulation (Gallo et al., 2009, 2012). Further studies have found that compared to goal intentions, IIR can significantly reduce individuals' self-reported negative emotion ratings without increasing cognitive load (decreased cognitive effort, no enhanced prefrontal activation) (Chen et al., 2021). Compared to intentional cognitive reappraisal, IIR can also down-regulate negative emotions more quickly and effectively without increasing cognitive load, as evidenced by reduced frontal and early centro-parietal LPP amplitudes (Chen et al., 2020). Additionally, research has shown that with equivalent cognitive effort, IIR significantly reduces individuals' valence ratings for negative pictures compared to intentional cognitive reappraisal and passive viewing, and this strategy demonstrates superior emotion regulation effects in depressed populations (陈圣栋, 2020). Thus, the unique advantage of IIR lies not only in achieving emotion regulation goals faster and more effectively without increasing cognitive load but also in helping populations with impaired cognitive abilities adaptively regulate negative emotions.

IIR may continuously regulate negative emotions (Chen et al., 2020; Huang et al., 2020), primarily manifested in its generalization and sustainable effects. The generalization effect refers to the phenomenon where IIR' s regulation of negative emotions in specific situations extends to non-specific situations, while the sustainable effect refers to the continued manifestation of IIR' s regulation of negative emotions. Huang et al. (2020) randomly assigned participants to IIR, goal intention, and control groups, using bloody and non-bloody (fearful) pictures as specified and unspecified negative situations, respectively, to explore the generalization effect of IIR in negative emotions. The specified situation refers to the "If" situation designated by the implementation intention (e.g., the bloody situation indicated by "If I see blood"), whereas the unspecified situation represents a generalized situation not designated by the implementation intention. Results showed that the IIR group reported lower negative emotional experiences in the specified negative situation compared to the control group, and the IIR learned in this situation could effectively regulate negative emotions elicited in the unspecified negative situation, demonstrating the generalization effect of IIR. Meanwhile, Chen et al. (2020) used EEG technology combined with a picture-viewing task to investigate IIR' s regulation effects on negative emotions. Findings revealed that IIR regulated individuals' negative emotions earlier and more persistently than intentional cognitive reappraisal, with the IIR group showing significantly reduced LPP amplitudes from 300–1700 ms compared to the control group, whereas the intentional cognitive reappraisal group only showed significant reduction from 500–700 ms. More importantly, when participants viewed bloody stimuli again after 20 minutes, IIR could still down-regulate negative emotions, suggesting that IIR' s generalization effect may have sustainability, though systematic investigation through longitudinal tracking methods is still needed.

Notably, although previous research has focused on the generalization effect of IIR emotion regulation, few studies have examined whether this generalization effect is sustainable. Moreover, prior research on generalization effects has relied on subjective reports without objective neurophysiological indicators, and examinations of sustainable effects have been limited to relatively short periods after strategy formation (approximately 20 minutes), leaving unclear whether the emotion regulation effects and generalization effects are truly sustainable. Therefore, this study aimed to longitudinally investigate IIR' s emotion regulation effects on participants in the present and over the following week by combining subjective self-reported valence and arousal ratings with EEG indicators (LPP). Specifically, after participants successfully learned the IIR strategy (Day 0), their subjective emotional experiences (valence and arousal) when viewing different negative emotional stimuli (specified vs. unspecified situations) were measured on Days 1, 3, 5, and 7, while their EEG activity was recorded on Days 3 and 7.

In this study, the EEG indicator focused on LPP amplitude under different conditions. The LPP is a positive-going late ERP component appearing approximately 300 ms after stimulus onset and represents one of the important neural markers for emotion regulation research (Dennis & Hajcak, 2009; Foti & Hajcak, 2008; Horan et al., 2013; Schönfelder et al., 2014). The psychological significance of LPP may differ across regions. The centro-parietal LPP is positively correlated with emotional experience intensity, with its amplitude decreasing during negative emotion down-regulation and increasing during up-regulation (Cuthbert et al., 2000; Li et al., 2022; Schönfelder et al., 2014). In contrast, the frontal LPP serves as an effective indicator of cognitive effort, with greater amplitude reflecting more cognitive effort (Chen et al., 2020; Moser et al., 2014; Shafir et al., 2015). Therefore, this study used centro-parietal and frontal LPP as physiological indicators of emotion regulation and cognitive effort, respectively. Additionally, previous research has shown sex differences in negative emotion susceptibility and emotion regulation. For example, women exhibit higher susceptibility to negative emotions than men (Rozin et al., 1999; Yuan et al., 2009) and have a higher risk of developing emotional problems or disorders (Daly, 2022; Zhang, R., et al., 2023). Furthermore, women are less effective than men at using cognitive reappraisal strategies to regulate negative emotions (Domes et al., 2010), and some studies indicate that automatic emotion regulation effects are influenced by sex differences (Key et al., 2022). Consequently, this study only included female participants.

Previous studies have shown that in subjective reports, IIR can effectively reduce individuals' negative emotional experiences (e.g., Gallo et al., 2012; Ma et al., 2019) and produce generalization effects (Huang et al., 2020). In ERP studies, IIR leads to decreased centro-parietal LPP amplitude without increasing frontal LPP amplitude and demonstrates certain sustained regulation effects (Chen et al., 2020). Additionally, research has shown that implementation intentions have long-term sustained impacts in mental or psychological disorders (e.g., schizophrenia, eating disorders; Chen et al., 2019; O' connor et al., 2015; Tanis et al., 2022) and interpersonal interactions (Stern & West, 2014), indirectly suggesting that IIR may also have long-term sustained effects on negative emotions. Based on these findings, we hypothesized that IIR could continuously reduce individuals' negative emotional experiences, arousal levels, and LPP amplitudes, and that IIR' s generalization effect might be sustainable.

Methods

Participants

Prior to the experiment, sample size was estimated using G*Power 3.1.9.2 based on previous research with parameters of f = 0.25, $\alpha = 0.05$, and power = 0.8. The required sample size for a two-factor mixed design was 34. Given sex differences in negative emotion susceptibility and automatic emotion regulation (e.g., Key et al., 2022; Rozin et al., 1999; Yuan et al., 2009) and the higher risk of emotional problems or disorders in women (Daly, 2022; Zhang, R., et al., 2023), this study recruited 58 female participants. During the experiment, 5 participants withdrew, and 2 were excluded due to severe depressive symptoms or failure to complete questionnaires seriously, leaving 51 valid participants. All valid participants had normal or corrected-to-normal vision, no color weakness or blindness, were right-handed, and had no personal or family history of psychiatric disorders. Upon arrival at the laboratory, participants were randomly assigned to either the IIR group or the passive viewing group (control group). The IIR group consisted of 25 participants (M = 20.16, SD = 2.25), and the control group (CG) consisted of 26 participants (M = 19.46, SD = 1.39). During both the IIR acquisition and post-acquisition phases, the two groups showed no significant differences in emotional traits and states before each experimental session (see Appendix Table 1 and Table 2). All participants were informed about the main experimental procedures and read and signed informed consent forms. This study was approved by the Human Research Ethics Committee of Sichuan Normal University.

Materials

(1) Stimulus materials. Following previous research (Chen et al., 2020; Huang et al., 2020), bloody and non-bloody pictures served as specified and unspecified negative situations, respectively, and neutral pictures served as the control condition. Three types of pictures (200 each) were selected from the International Affective Picture System (IAPS; Lang et al., 1999), the Chinese Affective Picture System (CAPS; 白露等, 2005), and the internet. All pictures were adjusted to 540 × 405 pixels using Photoshop CC 2019. Before the formal experiment, 31 valid female participants were randomly recruited to rate 600 pictures on 9-point scales for valence (1 = extremely pleasant, 9 = extremely unpleasant), arousal (1 = extremely calm, 9 = extremely uncalm), bloodiness (1 = not bloody at all, 9 = extremely bloody), disgust (1 = not disgusting at all, 9 = extremely disgusting), and fear (1 = not fearful at all, 9 = extremely fearful). Based on the rating results (see Table 3), 350 pictures were selected as formal experimental materials (100 bloody, 100 non-bloody, and 150 neutral pictures). Bloody and non-bloody pictures had significantly higher valence, arousal, bloodiness, disgust, and fear ratings than neutral pictures (ps < 0.001, ds > 0.700), while bloody and non-bloody pictures only differed significantly in bloodiness ($p < 0.001$, $d = 2.587$). In the formal experiment, 30 pictures of each type were used. To avoid high repetition rates across experimental sessions, the picture repetition rate among the five experimental sessions was kept below 6%.

Table 3 Material Rating Results

Dimension	Bloody Pictures	Non-bloody Pictures	Neutral Pictures	p-value
Valence	7.47 (0.68)	7.43 (0.67)	1.46 (0.68)	< 0.001
Arousal	7.43 (0.67)	6.33 (1.66)	1.01 (0.03)	< 0.001
Bloodiness	6.18 (1.53)	2.51 (1.17)	1.10 (0.20)	< 0.001
Disgust	6.19 (1.70)	6.48 (1.51)	1.09 (0.20)	< 0.001
Fear	4.90 (1.88)	5.09 (1.77)	1.10 (0.20)	< 0.001

Note: Before the formal experiment, 37 female participants were randomly recruited for picture rating, but 6 were excluded due to equipment malfunction, leaving 31 valid participants. The p-value refers to the significance of differences between bloody and non-bloody pictures across rating dimensions.

(2) Positive and Negative Affect Schedule (PANAS). The Chinese version of PANAS, compiled by Watson et al. (1988) and revised by 黄丽等 (2003), was used to assess positive and negative affect states. The scale includes two dimensions: positive affect (PA) and negative affect (NA), with 20 items rated on a 5-point Likert scale (1 = very slightly or not at all, 5 = extremely). The scale demonstrates good reliability and validity in Chinese populations (黄丽等, 2003). The reliability and validity in this study are shown in Table 4 . Participants completed this scale before each experimental session (5 times total).

(3) State-Trait Anxiety Inventory (STAI). The Chinese version of STAI, compiled by Spielberger (1983) and translated by 汪向东等 (1999), was used to assess trait and state anxiety. The inventory includes the Trait Anxiety Inventory (TAI) and State Anxiety Inventory (SAI), with 40 items total. Each subscale contains 10 positive and 10 negative affect items rated on a 4-point Likert scale (1 = not at all, 4 = very much so), with positive affect items reverse-scored. The inventory has good reliability and validity and serves as an effective tool for anxiety assessment (汪向东等, 1999). The reliability and validity in this study are shown in Table 4. The trait anxiety subscale was only completed before the first experimental session (pre-IIR acquisition), while the state anxiety subscale was completed before each session (5 times total).

(4) Beck Depression Inventory Second Edition (BDI-II). The Chinese version of BDI-II, compiled by Beck et al. (1996) and translated by 王振等 (2011), was used to assess depressive symptoms. The inventory contains 21 items rated on a 0–3 scale, with total scores below 13 indicating no depressive symptoms. The scale has good reliability and validity for effectively assessing depressive symptoms (王振等, 2011). The reliability and validity in this study are shown in Table 4. This scale was only completed before the first experimental session.

(5) Emotion Expression Scale (EES). The EES, compiled by Kring et al. (1994), was used to assess emotional expressivity. The scale contains 17 items rated on a 6-point Likert scale (1 = never, 6 = always), with higher total scores indicating greater emotional expressivity. The reliability and validity in this study are shown in Table 4. This scale was only completed before the first experimental session.

(6) Emotion Regulation Questionnaire (ERQ). The Chinese version of ERQ, compiled by Gross and John (2003) and revised by 王力等 (2007), was used. The questionnaire includes two dimensions: cognitive reappraisal (6 items) and expressive suppression (4 items), rated on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The questionnaire has good reliability and validity as an effective tool for assessing emotion regulation (王力等, 2007). The reliability and validity in this study are shown in Table 4. Since IIR involves cognitive reappraisal, this study focused on the cognitive reappraisal dimension (ERQ-R), which was only completed before the first experimental session.

(7) Cognitive Flexibility Scale (CFS). The Chinese version of CFS, compiled by Martin and Rubin (1995) and translated and revised by 齐冰等 (2013), was used to assess cognitive flexibility. The scale contains 12 items rated on a 6-point Likert scale (1 = very much agree, 6 = very much disagree), with higher total scores indicating greater cognitive flexibility. The scale has good reliability and validity for effectively assessing cognitive flexibility (齐冰等, 2013). The reliability and validity in this study are shown in Table 4. This scale was only completed before the first experimental session.

Table 4 Reliability and Validity Test Results of Each Scale in This Study

Scale	Cronbach's α	KMO	Bartlett's Test	Cumulative Variance	Factor Loadings
PANAS (PA)	0.92	> 0.50	p < 0.001	61.86%	> 0.50
PANAS (NA)	0.92	> 0.50	p < 0.001	66.85%	> 0.50
STAI-Trait	0.89	> 0.50	p < 0.001	70.19%	> 0.50
STAI-State	0.81	> 0.50	p < 0.001	75.80%	> 0.50
BDI-II	0.89	> 0.50	p < 0.001	68.51%	> 0.50
EES	0.81	> 0.50	p < 0.001	65.83%	> 0.50
ERQ-Reappraisal	0.89	> 0.50	p < 0.001	64.49%	> 0.50
ERQ-Suppression	0.81	> 0.50	p < 0.001	61.86%	> 0.50
CFS	0.85	> 0.50	p < 0.001	66.85%	> 0.50

Note: PA = Positive Affect dimension of PANAS; NA = Negative Affect dimension of PANAS; ERQ-R = Cognitive Reappraisal dimension of ERQ; ERQ-S = Expressive Suppression dimension of ERQ. Principal component analysis with varimax rotation was used to obtain KMO values, Bartlett's test results, cumulative variance contribution of common factors (eigenvalues > 1), and factor loadings for all items.

Experimental Task

This study used the Self-Assessment Manikins Rating Task (SAM; Bradley & Lang, 1994) to examine IIR's regulation effects on negative emotions (see Figure 1 [Figure 1: see original paper]). The task consisted of 6 blocks (30 bloody, 30 non-bloody, and 30 neutral pictures), with each block randomly presenting 15 pictures of different types. There was a 1-minute rest period between every two blocks. As shown in Figure 1, a fixation point was first presented at the center of the screen for 2–4 s, followed by a 4 s picture presentation (bloody/non-bloody/neutral), after which participants sequentially rated valence and arousal (5 s each).

The experimental program was compiled using E-Prime 3 software and run on a 19-inch HP computer (HP Z22n G2; screen resolution 1920 × 1080, refresh rate 59 Hz, brightness 35) with a black background. Participants' valence (1 = very pleasant, 9 = very unpleasant) and arousal (1 = very calm, 9 = very uncalm) ratings for each picture (bloody vs. non-bloody vs. neutral) and their EEG activity were recorded. Participants completed the experiment in a soundproof individual laboratory with their eyes approximately 100 cm from the computer screen.

Experimental Procedure

IIR Acquisition Phase (Day 0): Before the formal experiment, participants completed informed consent forms, personal information sheets, and emotion-related questionnaires (see Appendix Table 1). All participants were then randomly assigned to either the IIR or control group. Participants in the IIR group silently formed an emotion regulation goal ("I will not feel disgusted") and established an implementation intention-based cognitive reappraisal ("If I see blood, then I will view it from a doctor' s perspective"), after which they silently wrote the statement: "I will not feel disgusted. If I see blood, then I will view it from a doctor' s perspective." The control group only read the experimental instructions ("Feel the pictures carefully and rate them"). Both groups then completed a practice SAM rating task (9 trials using non-experimental pictures), during which the IIR group was required to verbalize the learned IIR statement when viewing bloody pictures. Subsequently, both groups completed the formal experiment while their arousal ratings, valence ratings, and EEG activity for emotional pictures were measured. Finally, participants completed post-experiment questionnaires assessing cognitive effort and emotion regulation difficulty.

Post-IIR Acquisition Phase (Day 1, Day 3, Day 5, Day 7): The procedure was essentially the same as the IIR acquisition phase, with two differences. First, during the week following IIR acquisition (Days 1, 3, 5, and 7), both groups came to the laboratory to complete the PANAS, STAI-S, and SAM rating task, with EEG data recorded on Days 3 and 7. It is important to note that different picture materials were used in each of the five experimental sessions, with picture repetition rates kept below 6% across sessions. Second, to explore the long-term sustainable effects of IIR, participants in the IIR group received no further emotion regulation-related instructions during the post-acquisition phase.

EEG Data Collection and Processing

EEG data were recorded using a 64-channel Ag/AgCl electrode cap (international 10-20 system; Brain Products GmbH, Germany) at a sampling rate of 1000 Hz and bandpass filter of 0.1–100 Hz. Horizontal and vertical electrooculograms were placed at the outer canthus of the right eye and below the left eye, respectively. FCz served as the online reference electrode, and all electrode impedances were maintained below 5 kΩ.

EEG data were processed using EEGLAB (Delorme & Makeig, 2004) based on MATLAB 2021a through the following steps: electrode localization, restoration of online reference; removal of unused electrodes, offline re-referencing to bilateral mastoids (TP9, TP10), downsampling to 500 Hz; filtering (bandpass 0.1-40 Hz), epoching (-200 to 4000 ms), baseline correction (-200 to 0 ms). Subsequently, bad channels and epochs were interpolated or manually removed. Independent Component Analysis (ICA; Delorme et al., 2007) was performed to remove noise components (blinks, eye movements, head movements, etc.), and epochs with amplitudes exceeding $±$100 V were rejected (Righart & De Gelder, 2008; 王婷等, 2024). During the IIR acquisition phase, an average of 93.56% valid trials remained for the bloody condition, 92.95% for the non-bloody condition, and 92.88% for the neutral condition. During the post-IIR acquisition phase, an average of 92.88% valid trials remained for the bloody condition, 92.20% for the non-bloody condition, and 92.42% for the neutral condition. One participant' s data were excluded due to excessive artifacts (over 40%). Finally, ERP waveforms were obtained through averaging. Following previous research, the average amplitudes at FCz and Cz within 400–800 ms and 800–1100 ms time windows were used as frontal LPP amplitudes at different time points (Ma et al., 2019; Shafir et al., 2015; Zhang, Y., et al., 2023). The average amplitudes at CPz within 400–600 ms, 600–1000 ms, 1000–1500 ms, 1500–2000 ms, 2000–2500 ms, 2500–3000 ms, 3000–3500 ms, and 3500–4000 ms time windows were used as centro-parietal LPP amplitudes at different time points (Dennis & Hajcak, 2009; Weinberg & Hajcak, 2010; Zhang, Y., et al., 2023).

Statistical Analysis

Statistical analyses were conducted using SPSS 27.0 (IBM, Somers, USA). First, to ensure that emotional pictures effectively induced negative emotions, a one-way repeated measures ANOVA was performed on control group participants' subjective ratings of emotional stimuli during the IIR acquisition phase, with picture type (bloody vs. non-bloody vs. neutral) as the independent variable and arousal and valence ratings as dependent variables. Second, following previous research (Denny et al., 2015; Liang et al., 2023), repeated measures ANOVAs were conducted for both the IIR acquisition and post-acquisition phases, with group (IIR vs. control) and picture type (bloody vs. non-bloody vs. neutral) as independent variables and arousal, valence ratings, and LPP amplitudes as dependent variables. Additionally, at each time point (Day 0, Day 1, Day 3, Day 5, Day 7), independent samples t-tests were performed on cognitive effort and emotion regulation difficulty ratings between the two groups, followed by correlation analyses between arousal, valence, and centro-parietal LPP. The significance level was set at $\alpha = 0.05$ (two-tailed). Greenhouse-Geisser correction was applied for repeated measures ANOVAs when sample sizes were unequal, and Bonferroni correction was used for post-hoc comparisons.

Results

Manipulation Check

To ensure that emotional pictures effectively induced negative emotions, a one-way repeated measures ANOVA was conducted on control group participants' (n

= 25) subjective ratings of emotional stimuli during the IIR acquisition phase. Results showed significant main effects of picture type on both arousal and valence (see Figure 2 [Figure 2: see original paper]): arousal, $F(2, 48) = 285.63$, $p < 0.001$, $^{2}p = 0.922$; valence, $F(2, 48) = 85.02$, $p < 0.001$, $^{2}p = 0.780$. Post-hoc comparisons revealed no significant differences between bloody and non-bloody pictures in arousal ($p = 0.999$) or valence ($p = 0.999$) ratings, but both were significantly higher than neutral pictures ($ps < 0.001$), confirming effective emotion induction.

Subjective Report Results

In the subjective report analysis, 2 participants were excluded due to equipment malfunction, leaving 49 valid participants (24 in the IIR group, M = 20.21, SD = 2.28; 25 in the control group, M = 19.44, SD = 1.42).

IIR Acquisition Phase (Day 0) Separate 2 (group: IIR vs. control) × 3 (picture type: bloody vs. non-bloody vs. neutral) repeated measures ANOVAs were conducted with valence and arousal as dependent variables. Results showed significant main effects of group (arousal: $F(1, 47) = 10.60$, $p = 0.002$, $^{2}p = 0.184$; valence: $F(1, 47) = 8.26$, $p = 0.006$, $^{2}p = 0.150$) and picture type (arousal: $F(2, 94) = 289.60$, $p < 0.001$, $^{2}p = 0.860$; valence: $F(2, 94) = 162.34$, $p < 0.001$, $^{2}p = 0.775$). Additionally, significant group × picture type interactions were found (see Figure 3 [Figure 3: see original paper]A): arousal, $F(2, 94) = 5.83$, $p = 0.007$, $^{2}p = 0.110$; valence, $F(2, 94) = 2.16$, $p = 0.030$, $^{2}p = 0.081$. Simple effects analysis revealed that the IIR group showed lower arousal (bloody: $p = 0.002$; non-bloody: $p = 0.005$) and negative emotional experience (bloody: $p < 0.001$; non-bloody: $p = 0.054$) compared to the control group in both bloody and non-bloody conditions, but no significant group differences were found in the neutral condition (arousal: $p = 0.110$; valence: $p = 0.575$). These results indicate that IIR can effectively regulate negative emotions and produce generalization effects.

Post-IIR Acquisition Phase Following the same approach as the acquisition phase, separate 2 (group: IIR vs. control) × 3 (picture type: bloody vs. non-bloody vs. neutral) repeated measures ANOVAs were conducted with valence and arousal as dependent variables.

Day 1: Results showed significant main effects of group (arousal: $F(1, 47) = 19.42$, $p < 0.001$, $^{2}p = 0.292$; valence: $F(1, 47) = 26.26$, $p < 0.001$, $^{2}p = 0.358$) and picture type (arousal: $F(2, 94) = 110.11$, $p < 0.001$, $^{2}p = 0.701$; valence: $F(2, 94) = 72.56$, $p < 0.001$, $^{2}p = 0.607$). Additionally, a significant group × picture type interaction was found for arousal, $F(2, 94) = 3.93$, $p = 0.045$, $^{2}p = 0.077$, and a marginally significant interaction for valence, $F(2, 94) = 3.23$, $p = 0.067$, $^{2}p = 0.064$. Simple effects analysis (see Figure 3B) revealed that the IIR group showed lower arousal ($ps < 0.001$) and negative emotional experience ($ps < 0.001$) compared to the control group in both bloody and non-bloody conditions, but no significant group differences were found in the neutral condition (arousal: $p = 0.159$; valence: $p = 0.190$).

Day 3: Results showed significant main effects of group (arousal: $F(1, 47) = 28.17$, $p < 0.001$, $^2p = 0.375$; valence: $F(1, 47) = 19.34$, $p < 0.001$, $^2p = 0.291$) and picture type (arousal: $F(2, 94) = 320.79$, $p < 0.001$, $^2p = 0.872$; valence: $F(2, 94) = 150.23$, $p < 0.001$, $^2p = 0.762$). Additionally, significant group × picture type interactions were found: arousal, $F(2, 94) = 16.15$, $p < 0.001$, $^2p = 0.256$; valence, $F(2, 94) = 10.48$, $p < 0.001$, $^2p = 0.182$. Simple effects analysis (see Figure 3B) revealed that the IIR group showed lower arousal (ps < 0.001) and negative emotional experience (ps < 0.001) compared to the control group in both bloody and non-bloody conditions, but no significant group differences were found in the neutral condition (arousal: $p = 0.107$; valence: $p = 0.554$).

Day 5: Results showed significant main effects of group (arousal: $F(1, 47) = 30.11$, $p < 0.001$, $^2p = 0.390$; valence: $F(1, 47) = 29.24$, $p < 0.001$, $^2p = 0.384$) and picture type (arousal: $F(2, 94) = 95.26$, $p < 0.001$, $^2p = 0.670$; valence: $F(2, 94) = 67.38$, $p < 0.001$, $^2p = 0.589$). Additionally, a significant group × picture type interaction was found for arousal, $F(2, 94) = 6.93$, $p = 0.007$, $^2p = 0.128$, and a marginally significant interaction for valence, $F(2, 94) = 3.26$, $p = 0.066$, $^2p = 0.065$. Simple effects analysis (see Figure 3B) revealed that the IIR group showed lower arousal (ps < 0.001) and negative emotional experience (ps < 0.001) compared to the control group in both bloody and non-bloody conditions, but no significant group differences were found in the neutral condition (arousal: $p = 0.127$; valence: $p = 0.267$).

Day 7: Results showed significant main effects of group (arousal: $F(1, 47) = 38.83$, $p < 0.001$, $^2p = 0.452$; valence: $F(1, 47) = 34.01$, $p < 0.001$, $^2p = 0.420$) and picture type (arousal: $F(2, 94) = 315.93$, $p < 0.001$, $^2p = 0.870$; valence: $F(2, 94) = 132.17$, $p < 0.001$, $^2p = 0.738$). Additionally, significant group × picture type interactions were found: arousal, $F(2, 94) = 32.97$, $p < 0.001$, $^2p = 0.412$; valence, $F(2, 94) = 13.76$, $p < 0.001$, $^2p = 0.226$. Simple effects analysis (see Figure 3B) revealed that the IIR group showed lower arousal (ps < 0.001) and negative emotional experience (ps < 0.001) compared to the control group in both bloody and non-bloody conditions, but no significant group differences were found in the neutral condition (arousal: $p = 0.530$; valence: $p = 0.486$).

These results indicate that from Days 1 to 7 post-IIR acquisition, IIR could continuously reduce arousal levels and negative emotional experiences, with certain generalization effects that were relatively stable for arousal (but not valence).

ERP Results

In the EEG data analysis, 4 participants' data were lost due to equipment malfunction or improper data collection, and 1 participant was excluded due to excessive artifacts (over 40%). The final sample included 22 participants in the IIR group ($M = 20.32$, $SD = 2.34$) and 22 in the control group ($M = 19.50$, $SD = 1.47$).

IIR Acquisition Phase (Day 0) Separate 2 (group: IIR vs. control) × 3 (picture type: bloody vs. non-bloody vs. neutral) repeated measures ANOVAs were conducted with frontal LPP and centro-parietal LPP at different time windows as dependent variables.

Frontal LPP: In the 400–800 ms window, a significant main effect of group was found (see Figure 4 [Figure 4: see original paper]A, 4B), $F(1, 42) = 9.62$, $p = 0.003$, ^{2}p = 0.186, with the IIR group showing significantly smaller frontal LPP amplitude than the control group. The main effect of picture type was also significant, $F(2, 84) = 22.88$, $p < 0.001$, ^{2}p = 0.353, with bloody pictures eliciting significantly larger frontal LPP than non-bloody and neutral pictures, and non-bloody pictures eliciting larger frontal LPP than neutral pictures. However, the group × picture type interaction was not significant ($p = 0.318$).

In the 800–1100 ms window, significant main effects of group, $F(1, 42) = 7.37$, $p = 0.010$, ^{2}p = 0.149, and picture type, $F(2, 84) = 51.86$, $p < 0.001$, ^{2}p = 0.553, were found. The group × picture type interaction was marginally significant, $F(2, 84) = 3.25$, $p = 0.052$, ^{2}p = 0.072. Simple effects analysis (see Figure 4A, 4B) revealed that the IIR group showed smaller frontal LPP amplitude than the control group in both bloody ($p = 0.006$) and non-bloody ($p = 0.004$) conditions, but no significant group difference was found in the neutral condition ($p = 0.190$).

Centro-parietal LPP: Results for main effects and interactions across time windows are shown in Table 5 . The main effect of group was significant from 400–2500 ms ($ps < 0.050$), the main effect of picture type was significant across all time windows ($ps < 0.001$; means and SDs are in Appendix Table 7), and the group × picture type interaction was significant from 1000–2000 ms (1000–1500 ms: $F(2, 84) = 4.16$, $p = 0.023$, ^{2}p = 0.090; 1500–2000 ms: $F(2, 84) = 3.36$, $p = 0.043$, ^{2}p = 0.074). Simple effects analysis (see Figure 4A, 4B) revealed that in the 1000–1500 ms window, the IIR group showed significantly smaller centro-parietal LPP amplitude than the control group in both bloody ($p = 0.002$) and non-bloody ($p = 0.005$) conditions, but no group difference was found in the neutral condition ($p = 0.421$). In the 1500–2000 ms window, the IIR group showed significantly smaller centro-parietal LPP amplitude than the control group in both bloody ($p = 0.006$) and non-bloody ($p = 0.029$) conditions, but no group difference was found in the neutral condition ($p = 0.642$).

These results further indicate that the IIR group successfully learned IIR with less cognitive resource consumption and that IIR produced certain generalization effects.

Post-IIR Acquisition Phase Day 3: Using the same method, results (see Table 6) showed significant main effects of group and picture type on frontal LPP (400–1100 ms). In the 400–800 ms window, a significant main effect of group was found (see Figure 5 [Figure 5: see original paper]A, 5B), $F(1, 42) = 7.97$, $p = 0.007$, ^{2}p = 0.159, with the IIR group showing significantly smaller frontal LPP amplitude than the control group. The main effect of picture type was significant, F(2, 84) = 26.97, p < 0.001, ^{2}p = 0.391, with bloody and non-bloody pictures eliciting no significant difference in frontal LPP amplitude, but both eliciting significantly larger amplitudes than neutral pictures. However, the group × picture type interaction was not significant (p = 0.770). Similarly, in the 800-1100 ms window, a significant main effect of group was found (see Figure 5A, 5B), F(1, 42) = 6.42, p = 0.015, ^{2}p = 0.133, with the IIR group showing significantly smaller frontal LPP amplitude than the control group. The main effect of picture type was significant, F(2, 84) = 61.66, p < 0.001, ^{2}p = 0.595, with bloody and non-bloody pictures eliciting no significant difference in frontal LPP amplitude, but both eliciting significantly larger amplitudes than neutral pictures. However, the group × picture type interaction was not significant (p = 0.793).

Given that the IIR acquisition phase found the IIR group' s centro-parietal LPP amplitude was significantly smaller than the control group' s only from 400-2500 ms, the post-acquisition phase focused on this time window for sustained regulation effects. Results for main effects and interactions across time windows are shown in Table 6. The main effect of group was significant from 400-600 ms (F(1, 42) = 16.10, p < 0.001, ^{2}p = 0.277), 600-1000 ms (F(1, 42) = 13.08, p < 0.001, ^{2}p = 0.238), and 1000-1500 ms (F(1, 42) = 5.19, p = 0.028, ^{2}p = 0.110), all showing significantly smaller centro-parietal LPP amplitude in the IIR group (means and SDs are in Table 6). The main effect of picture type was significant across all time windows (ps < 0.001; means and SDs are in Appendix Table 7). However, the group × picture type interaction was not significant (ps > 0.300).

Day 7: Using the same method, results (see Table 6) showed significant main effects of group and picture type on frontal LPP (400-1100 ms). In the 400-800 ms window, a significant main effect of group was found (see Figure 5C, 5D), F(1, 42) = 4.93, p = 0.032, ^{2}p = 0.105, with the IIR group showing significantly smaller frontal LPP amplitude than the control group. The main effect of picture type was significant, F(2, 84) = 17.22, p < 0.001, ^{2}p = 0.291, with bloody and non-bloody pictures eliciting no significant difference in frontal LPP amplitude, but both eliciting significantly larger amplitudes than neutral pictures. However, the group × picture type interaction was not significant (p = 0.183). Similarly, in the 800-1100 ms window, a significant main effect of group was found (see Figure 5C, 5D), F(1, 42) = 5.26, p = 0.027, ^{2}p = 0.111, with the IIR group showing significantly smaller frontal LPP amplitude than the control group. The main effect of picture type was significant, F(2, 84) = 44.26, p < 0.001, ^{2}p = 0.513, with bloody and non-bloody pictures eliciting no significant difference in frontal LPP amplitude, but both eliciting significantly larger amplitudes than neutral pictures. However, the group × picture type interaction was not significant (p = 0.304).

For centro-parietal LPP (400-2500 ms), significant main effects of group and picture type were found (ps < 0.050, see Table 6). The group × picture type interaction was only significant in the 400–600 ms window, $F(2, 84) = 3.35$, $p = 0.043$, $^{2}p = 0.074$. Simple effects analysis (see Figure 5C, 5D) revealed that the IIR group showed significantly smaller centro-parietal LPP amplitude than the control group in bloody ($p = 0.020$), non-bloody ($p < 0.001$), and neutral ($p = 0.037$) conditions.

These results indicate that from Days 1 to 7 post-IIR acquisition, IIR could continuously reduce frontal LPP (400–1100 ms) and centro-parietal LPP (400–1500 ms) amplitudes, but the sustained generalization effect was unstable, appearing only in the centro-parietal LPP (400–600 ms) on Day 7.

Post-Experiment Survey Results

During the IIR acquisition phase, no significant differences were found between the IIR and control groups in reported cognitive effort ($t(47) = -0.92$, $p = 0.362$, $d = 0.263$) or emotion regulation difficulty ($t(47) = -0.06$, $p = 0.949$, $d = 0.018$). During the post-IIR acquisition phase, a trend emerged where the IIR group' s cognitive effort and emotion regulation difficulty ratings gradually became lower than the control group' s (see Figure 6 [Figure 6: see original paper]). **Day 1:** No significant differences were found between groups in cognitive effort ($t(47) = -1.80$, $p = 0.078$, $d = 0.514$) or emotion regulation difficulty ($t(47) = -1.27$, $p = 0.209$, $d = 0.364$). **Day 3:** The IIR group reported significantly lower cognitive effort than the control group ($t(47) = -2.36$, $p = 0.023$, $d = 0.673$), but no significant group difference in emotion regulation difficulty ($t(47) = -0.64$, $p = 0.528$, $d = 0.182$). **Day 5:** The IIR group reported significantly lower cognitive effort and emotion regulation difficulty than the control group (cognitive effort: $t(47) = -3.41$, $p = 0.001$, $d = 0.974$; emotion regulation difficulty: $t(47) = -3.00$, $p = 0.004$, $d = 0.857$). **Day 7:** The IIR group reported significantly lower cognitive effort than the control group ($t(47) = -2.30$, $p = 0.026$, $d = 0.656$), but no significant group difference in emotion regulation difficulty ($t(47) = -1.79$, $p = 0.081$, $d = 0.510$).

Correlation Analysis Results

Following Yang et al. (2022), correlation analysis was conducted between arousal and centro-parietal LPP (400–2500 ms). Results showed a significant positive correlation between arousal and centro-parietal LPP amplitude, $\beta = 0.83$, $p < 0.001$, 95% CI = [0.40, 1.26] (after removing one outlier beyond 3 SD).

Some studies have found no significant correlation between valence and LPP amplitude (Hajcak et al., 2006; Schubring & Schupp, 2019; Yen et al., 2010), while another study found that more negative valence was associated with larger LPP amplitude and more positive valence with larger LPP amplitude (Kessel, 2017). Based on these findings, we hypothesized a non-linear relationship between valence and LPP amplitude, which was tested using non-linear regression analysis. Results showed no significant correlation between valence and centro-parietal LPP (400–2500 ms) amplitude, $\beta = 0.01$, $p = 0.804$, 95% CI = [-0.19, 0.24]. Thus, arousal and valence may show different correlation patterns with LPP.

Discussion

This study investigated the sustained regulation and generalization effects of IIR on negative emotions using both subjective self-reports and EEG technology. Results showed that from Day 0 to Day 7, compared to the control group, the IIR group showed continuously reduced emotional experience and arousal levels for specified negative situations (bloody pictures), and this regulation effect also appeared consistently in arousal ratings for unspecified situations (non-bloody pictures). Furthermore, on Days 0, 3, and 7, the IIR group showed reduced centro-parietal LPP (400–1500 ms) and frontal LPP (400–1100 ms) amplitudes compared to the control group, with a significant positive correlation between centro-parietal LPP amplitude and arousal. Together, these findings demonstrate that IIR can sustainably regulate negative emotions and produce generalization effects, with the generalization effect showing some persistence.

Previous research has identified centro-parietal LPP and frontal LPP as effective indicators of emotional experience intensity (Cuthbert et al., 2000; Hajcak et al., 2010; Shafir et al., 2016) and cognitive effort (Shafir et al., 2015; Wang et al., 2022), respectively. For example, individuals' centro-parietal LPP amplitude shows a significant positive correlation with arousal (Cuthbert et al., 2000), and evidence suggests that reduced arousal following automatic emotion regulation strategies is accompanied by decreased centro-parietal LPP amplitude (Chen et al., 2020), while increased cognitive effort during cognitive reappraisal is accompanied by increased frontal LPP amplitude (Moser et al., 2014; Wang et al., 2022). Consistent with previous research (e.g., Cuthbert et al., 2000), this study found a significant linear positive correlation between centro-parietal LPP amplitude and arousal, providing additional empirical evidence for the validity of centro-parietal LPP as a marker of emotional intensity. This study also found that IIR simultaneously reduced both centro-parietal and frontal LPP amplitudes elicited by negative scenes, indicating that IIR effectively regulated negative emotions without increasing cognitive effort.

Furthermore, previous research has shown that IIR emotion regulation effects learned in specific negative situations generalize to non-specific negative situations (Huang et al., 2020). Building on this, we not only replicated the generalization effect of IIR but also found that this generalization effect has some persistence, as evidenced by continuously reduced arousal levels for both specified (bloody pictures) and unspecified situations from Day 0 to Day 7. This may occur because individuals continuously establish "goal + situation" connections that transfer to other similar situations during persistent practice (Bieleke et al., 2018). This finding has several innovative implications. First, it may advance and refine automatic emotion regulation theory. Specifically, our results not only support the auto-motive model of nonconscious goal pursuit (Bargh, 1990; Bargh & Williams, 2007) but also contribute to its development. The auto-motive model emphasizes that automatic emotion regulation can automatically, continuously, and stably establish a "goal + situation" connection to persistently regulate negative emotions. Our study further demonstrates that IIR' s generalization effect has some persistence and can function continuously across different negative situations. This finding provides a new perspective for future research, suggesting that subsequent studies should deeply explore the underlying mechanisms of this phenomenon to expand and integrate theory. Second, it may promote intervention and treatment for emotional disorders. Some studies have noted that a typical characteristic of depressed individuals is a lack of cognitive effort (Horne et al., 2021; Tran et al., 2021). Previous research has found that IIR can help depressed individuals adaptively regulate negative emotions (陈圣栋, 2020). However, the regulatory effect of IIR in individuals with comorbid depression and anxiety remains unclear. Yuan et al. (2023) found that automatic emotion regulation (vs. intentional emotion regulation) showed decreased subjective emotion ratings and LPP amplitudes in healthy, subclinical depression, and clinical depression groups, indicating cross-population stability of automatic emotion regulation. Our exploratory analysis also supported this conclusion, showing no significant differences in IIR' s emotion regulation effects between high and low anxiety or depression individuals (see Supplementary Materials). This suggests that IIR may play a role in treating comorbid anxiety and depression. However, since our exploratory analysis was based on a small sample, these findings require further verification to provide more adequate empirical support for precision interventions.

Nevertheless, the sustained generalization of IIR only appeared stably for arousal (not valence), suggesting that the persistence of IIR' s generalization effect may have boundary conditions that require further verification. This result may occur because arousal and valence have certain differences. Some studies have found that although arousal and valence are correlated, they can be dissociated in physiological responses (Kron et al., 2015; Lang et al., 1993), and their correlation in self-reports is limited (Ito et al., 1998) with some differences (see Section 3.5 correlation analysis results). Another reason may be that IIR' s generalization process is influenced by the degree of automaticity. Specifically, for arousal and centro-parietal LPP, IIR' s generalization effect showed a gradually strengthening trend over time. This was reflected in arousal ratings, where the IIR group (vs. control group) showed a decreasing trend in emotional intensity ratings for non-bloody pictures over time, and in centro-parietal LPP, where the time course of IIR' s generalization effect accelerated. That is, during the IIR acquisition phase, IIR' s generalization effect appeared from 1000–2000 ms, while during the post-acquisition phase (Day 7), it appeared from 400–600 ms. This suggests that as automaticity deepens, the generalization effect strengthens. Therefore, future research should investigate the boundary conditions for IIR' s sustainable generalization.

Another innovative aspect of this study is that previous research only examined IIR' s sustained effects over relatively short periods (Chen et al., 2020, 2021), whereas this study combined subjective reports and EEG technology in a longitudinal design to find that IIR' s regulation of negative emotions has durability (stability), with effective regulation (continuously reduced arousal, negative emotional experience, and centro-parietal LPP amplitude) still present one week later. This extends previous research (Chen et al., 2020, 2021; Gallo et al., 2009) and provides additional empirical support for IIR' s effectiveness and stability. The temporal processing model of controlled-automatic emotion regulation posits that automatic emotion regulation not only acts earlier than intentional emotion regulation but also lasts longer (Chen et al., 2020; 陈圣栋, 2020). Although this study did not compare IIR with intentional emotion regulation, it provides some evidence for this model by confirming IIR' s relatively persistent duration. However, to better verify and refine the temporal processing model of controlled-automatic emotion regulation, future studies should consider comparing IIR with intentional emotion regulation and examining differences in their sustained regulation and generalization effects and underlying mechanisms.

This study has several limitations. First, it only used a female sample with a relatively small sample size, which may limit generalizability. Future research should consider including male participants and increasing sample size to examine sex differences in IIR' s sustained regulation of negative emotions. Second, the time frame for examining IIR' s sustained regulation and generalization effects (one week) was relatively short and insufficient to identify boundary conditions. Future studies should extend the time frame and compare IIR' s emotion regulation effects across different time periods to facilitate IIR interventions and clinical applications. Third, some studies have noted that practice enhances automatic emotion regulation effects (Christou-Champi et al., 2015; 陈圣栋, 2020). This study had relatively few practice trials, and future research should consider increasing practice frequency or comparing IIR' s sustained regulation and generalization effects across different practice frequencies. Fourth, due to research purposes, relevant literature, and practical constraints (e.g., time and participant recruitment difficulty), this study only compared the IIR and control groups. Future research should consider including intentional cognitive reappraisal for comparison with IIR to enhance the persuasiveness of findings.

In conclusion, this study combined subjective self-reports and EEG technology to longitudinally investigate the sustainability of IIR' s emotion regulation and generalization effects. The core findings demonstrate that IIR can sustainably regulate negative emotions and produce generalization effects, with the generalization effect showing some persistence. These findings have important implications for advancing and refining automatic emotion regulation theory and provide clinical guidance for interventions targeting emotional disorders.

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Appendix Tables

Table 1 Participants' Emotional Traits and States Before IIR Acquisition

Variable	IIR (n = 25)	CG (n = 26)	Cohen' s d
Age	20.16 (2.25)	19.46 (1.39)	-
Trait Anxiety	25.24 (7.48)	27.04 (7.42)	-
State Anxiety	13.16 (4.50)	14.46 (4.64)	-
Positive Affect	35.76 (8.56)	36.08 (7.15)	-
Negative Affect	39.12 (8.63)	39.35 (7.30)	-
Depression	4.40 (4.79)	5.08 (5.28)	-
Emotion Expression	64.84 (13.45)	61.88 (13.13)	-
Cognitive Reappraisal	32.28 (6.03)	32.65 (5.89)	-
Cognitive Flexibility	34.16 (7.49)	35.58 (7.06)	-

Note: All variables are presented as mean (SD); IIR = Implementation Intention-Based Reappraisal group; CG = Control group; the same below.

Table 2 Participants' Emotional States Before Each Experimental Session in the Post-IIR Acquisition Phase

Variable	IIR (n = 25)	CG (n = 26)	Cohen' s d
PA-Day1	24.72 (9.05)	24.08 (8.51)	-
PA-Day3	23.80 (9.07)	24.04 (8.75)	-
PA-Day5	13.28 (4.37)	11.96 (2.59)	-
PA-Day7	12.24 (3.49)	11.87 (3.05)	-
NA-Day1	35.40 (7.72)	36.04 (8.25)	-
NA-Day3	36.24 (7.99)	35.29 (7.83)	-
NA-Day5	26.27 (7.90)	25.92 (8.45)	-
NA-Day7	26.19 (7.88)	24.67 (7.47)	-
SAI-Day1	13.46 (3.88)	12.62 (3.15)	-
SAI-Day3	12.73 (3.80)	12.79 (3.60)	-
SAI-Day5	36.27 (8.42)	36.65 (7.42)	-
SAI-Day7	36.35 (7.68)	37.64 (8.28)	-

Note: PA = Positive Affect; NA = Negative Affect; SAI = State Anxiety Inventory; Day1, 3, 5, 7 represent Days 1, 3, 5, and 7 post-IIR acquisition; PA-Day7 and NA-Day7 are missing 4 data points (IIR group n = 23, control group n = 24); SAI-Day7 is missing 2 data points (IIR group n = 24, control group n = 25); Bonferroni correction was applied to all results.

Table 7 Main Effects of Picture Type on Frontal and Centro-parietal LPP Across Time Windows During IIR Acquisition and Post-Acquisition Phases

LPP Time Window	Bloody	Non-bloody	Neutral	p-value
Day0 Frontal LPP 400–800ms	3.98 (6.49)	2.59 (5.72)	0.22 (6.06)	< 0.001
Day0 Frontal LPP 800–1100ms	6.04 (5.78)	5.82 (5.66)	0.62 (5.13)	< 0.001
Day0 Centro-parietal LPP 400–600ms	7.98 (5.37)	5.99 (4.88)	3.44 (4.88)	< 0.001
Day0 Centro-parietal LPP 600–1000ms	8.29 (5.41)	7.48 (5.13)	2.72 (4.50)	< 0.001
Day0 Centro-parietal LPP 1000–1500ms	5.78 (4.83)	6.48 (4.37)	0.33 (4.49)	< 0.001
Day0 Centro-parietal LPP 1500–2000ms	5.39 (4.83)	5.86 (4.39)	-0.42 (4.46)	< 0.001
Day0 Centro-parietal LPP 2000–2500ms	4.97 (5.10)	4.99 (4.56)	-0.05 (4.04)	< 0.001
Day0 Centro-parietal LPP 2500–3000ms	4.67 (5.37)	4.33 (4.39)	-0.46 (3.63)	< 0.001
Day0 Centro-parietal LPP 3000–3500ms	4.16 (5.23)	3.10 (4.98)	-1.03 (3.29)	< 0.001
Day0 Centro-parietal LPP 3500–4000ms	3.28 (5.22)	2.34 (4.79)	-1.42 (3.46)	< 0.001
Day3 Frontal LPP 400–800ms	0.85 (5.76)	0.94 (5.80)	-2.07 (5.33)	< 0.001
Day3 Frontal LPP 800–1100ms	4.31 (4.28)	4.74 (4.79)	-0.31 (4.35)	< 0.001
Day3 Centro-parietal LPP 400–600ms	4.24 (5.81)	3.62 (5.40)	1.07 (4.83)	< 0.001
Day3 Centro-parietal LPP 600–1000ms	6.28 (4.55)	6.60 (4.63)	1.32 (3.96)	< 0.001
Day3 Centro-parietal LPP 1000–1500ms	5.17 (3.93)	5.40 (4.38)	0.26 (3.80)	< 0.001
Day3 Centro-parietal LPP 1500–2000ms	4.64 (3.66)	4.79 (4.86)	-0.08 (4.19)	< 0.001

LPP Time Window	Bloody	Non-bloody	Neutral	p-value
Day3 Centro-parietal LPP 2000–2500ms	3.59 (3.85)	4.10 (5.02)	-0.57 (4.27)	< 0.001
Day7 Frontal LPP 400–800ms	-0.31 (6.37)	-0.05 (5.48)	-2.71 (5.00)	< 0.001
Day7 Frontal LPP 800–1100ms	3.67 (5.52)	4.24 (4.60)	-0.92 (3.63)	< 0.001
Day7 Centro-parietal LPP 400–600ms	2.42 (6.24)	2.47 (5.44)	0.44 (4.87)	< 0.001
Day7 Centro-parietal LPP 600–1000ms	4.57 (5.09)	5.45 (4.53)	1.09 (3.54)	< 0.001
Day7 Centro-parietal LPP 1000–1500ms	4.11 (4.48)	4.75 (4.18)	0.19 (3.80)	< 0.001
Day7 Centro-parietal LPP 1500–2000ms	3.05 (4.83)	3.63 (4.92)	-0.10 (4.17)	< 0.001
Day7 Centro-parietal LPP 2000–2500ms	2.45 (5.44)	2.46 (5.26)	0.06 (4.10)	< 0.001

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

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