Cognitive Neural Mechanisms of Implicit Emotion Regulation

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Abstract

Implicit emotion regulation is the process by which individuals change their emotions without conscious supervision or explicit intention to regulate emotions. Compared with explicit emotion regulation, implicit emotion regulation relies less on the prefrontal executive control system. Building upon the existing dichotomous classification of implicit emotion regulation, this paper proposes a new tripartite theoretical framework that categorizes implicit emotion regulation into three types: automatic, task-incidental, and implicit-goal-driven. Among them, automatic implicit regulation, exemplified by fear extinction, relies on the ventromedial prefrontal cortex to directly modulate the amygdala; task-incidental regulation occurs in tasks such as affect labeling and emotional Stroop, where the lateral prefrontal cortex incidentally regulates emotions through the cognitive control system during task execution; implicit-goal-driven regulation, through priming or implicit training, activates the pursuit of implicit emotion regulation goals, which can achieve automatic regulation via the ventromedial prefrontal cortex, and under certain conditions, recruit the cognitive control functions of the lateral prefrontal cortex to achieve controlled emotion regulation. Neuromodulation studies have confirmed that the ventromedial prefrontal cortex is a key causal brain region for implicit emotion regulation, and its functional enhancement holds promise for improving implicit emotion regulation abilities in patients with depression and anxiety. The tripartite theoretical framework proposed in this paper highlights the diverse mechanisms of implicit emotion regulation, expands the dynamic understanding of emotion regulation theory, and also provides a promising new avenue for clinical intervention in patients with emotional disorders.

Full Text

Preamble

Implicit emotion regulation refers to the process by which individuals modify their emotions without conscious monitoring or explicit intention to regulate. Compared to explicit emotion regulation, implicit emotion regulation relies less heavily on the prefrontal executive control system. Building upon existing dual-classification frameworks, this paper proposes a novel tripartite theoretical framework that categorizes implicit emotion regulation into three types: automatic, task-incidental, and implicit goal-driven regulation. Automatic implicit regulation, exemplified by fear extinction, depends on the ventromedial prefrontal cortex (VMPFC) directly modulating the amygdala. Task-incidental regulation occurs during tasks such as affect labeling and emotional Stroop, where lateral prefrontal regions incidentally regulate emotions through cognitive control systems during task execution. Implicit goal-driven regulation activates implicit emotion regulation goal pursuit through priming or implicit training, which can either utilize VMPFC for automatic regulation or recruit lateral prefrontal cognitive control functions under certain conditions to achieve controlled emotion regulation. Neuromodulation studies have confirmed that VMPFC is a critical causal brain region for implicit emotion regulation, and enhancing its function holds promise for improving implicit emotion regulation capacity in patients with depression and anxiety. The tripartite framework proposed herein highlights the diverse mechanisms underlying implicit emotion regulation, expands the dynamic understanding of emotion regulation theory, and provides promising new avenues for clinical intervention in mood disorders.

Emotion regulation refers to the process by which individuals influence which emotions they have, when they have them, and how they experience and express these emotions (Gross, 2015). Successful emotion regulation forms the foundation for maintaining mental and physical health as well as fostering positive interpersonal relationships (Aldao et al., 2010; Gross & John, 2003). In clinical practice, persistent negative emotional distress coupled with ineffective emotion regulation is considered a primary characteristic of patients with mood disorders such as depression and anxiety (Joormann & Stanton, 2016; Liu & Thompson, 2017). Most previous research has focused on explicit emotion regulation (Gao et al., 2022; Konrad et al., 2025; Lincoln et al., 2022)—emotion regulation processes driven by explicit goals to change emotions. In daily life, emotions persist and fluctuate continuously, yet both initiating and maintaining emotion regulation consciously rely on top-down cognitive control mechanisms that consume substantial cognitive resources (Ferri et al., 2016; Li et al., 2025; Li et al., 2023, 2024; Pruessner et al., 2020; Tang et al., 2025), leading to fatigue. In fact, most emotional changes occur not through subjective will and effort but through more adaptive means, which is where implicit emotion regulation plays a crucial role. Unlike explicit emotion regulation, implicit emotion regulation encompasses a broad category of emotion change methods that occur without explicit regulation goals, operating imperceptibly with concealed execution processes and unclear cognitive-neural mechanisms.

Numerous studies have confirmed that implicit emotion regulation effectively modulates negative emotional experiences and related physiological and behavioral responses, playing an important role in clinical interventions for mood disorders (see meta-analysis Dalton et al., 2025). Compared to explicit, effortful emotion regulation that requires conscious monitoring and consumes cognitive resources, implicit emotion regulation avoids adverse effects from conscious supervision and cognitive resource depletion, thus offering advantages in certain contexts. For example, implicit cognitive reappraisal proves more effective in individuals unaccustomed to cognitive reappraisal (Gao et al., 2024; Williams et al., 2009). When individuals experience anger that conflicts with the goal of down-regulating emotion, implicit emotion regulation can avoid conflict between regulation goals and subjective will, facilitating easier execution and achieving anger reduction (Mauss et al., 2007b). In complex tasks such as risk decision-making and mathematical learning, emotion regulation requiring cognitive supervision can impair task performance and produce inappropriate behavioral consequences, whereas implicit emotion regulation effectively modulates emotions with minimal impact on ongoing tasks (Yang et al., 2015; Yuan et al., 2019; Zhu et al., 2022). When regulating high-intensity negative emotions, implicit emotion regulation more effectively down-regulates subjective negative emotion reports and related EEG indices compared to explicit emotion regulation (Y. Zhang et al., 2023). For patients with psychiatric disorders such as depression and anxiety, impaired cognitive control resources limit the implementation of explicit emotion regulation, particularly cognitive reappraisal, yet implicit emotion regulation functions remain largely intact (Dalton et al., 2025; Li et al., 2023; Yuan et al., 2022; 莫李澄等, 2021; 张丹丹, 李思瑾, 2024). For instance, implicitly primed cognitive reappraisal strategies can help depressed patients reduce late positive potential (LPP) components related to negative emotions (Yuan et al., 2022) and can make anxiety patients' emotion ratings more positive (Gao et al., 2024).

In summary, investigating the cognitive and neural mechanisms of implicit emotion regulation can deepen emotion regulation theory and provide guidance for treating clinical mood disorders. This paper first proposes a tripartite classification of implicit emotion regulation, then uses this framework to review brain imaging and neuromodulation findings on implicit emotion regulation, and finally discusses the clinical application prospects for treating mood disorders.

2 A Tripartite Classification of Implicit Emotion Regulation

From a cognitive mechanism perspective, implicit emotion regulation involves multiple unconscious cognitive processes, including both fully automatic and top-down cognitive control-dependent regulation methods. Gyurak et al. (2011) proposed the "dual-process framework," which first divided emotion regulation into two categories (explicit and implicit), suggesting that implicit emotion regulation is automatically initiated by emotional stimuli without conscious monitoring and with unconscious execution—emphasizing its automatic nature compared to explicit emotion regulation. Braunstein et al. (2017) added an "emotion regulation goal" dimension to this framework, proposing a "multi-level framework" that views emotion regulation as a process of achieving emotion regulation goals. Thus, the "explicit" versus "implicit" nature of regulation goals and the "controlled" versus "automatic" nature of regulation execution constitute two orthogonal dimensions, with the primary distinction between implicit and explicit emotion regulation being the absence of explicit regulation goals in the former. Additional literature has discussed related classification frameworks (Koole et al., 2011, 2015; Mauss et al., 2007a). The multi-level framework first subdivided implicit emotion regulation into "implicit automatic"and "implicit controlled"subtypes. Implicit automatic emotion regulation involves no active control, with emotional change occurring alongside emotional learning/value updating processes, with fear extinction being a classic example. Implicit controlled emotion regulation requires active control participation, with emotional Stroop being a classic example—the task itself does not require emotion regulation, but because emotionally salient materials are used, task execution incidentally changes emotions.

Although the multi-level framework (Braunstein et al., 2017) deepens our understanding of emotion regulation, particularly implicit emotion regulation, its classification of emotion regulation is static and lacks consideration of dynamic changes. In reality, both goal and process dimensions exhibit dynamic variation. In the goal dimension, regulation goals can shift from explicit to implicit through priming. In the process dimension, the degree of cognitive control involvement changes dynamically with situational shifts and individuals' active adjustments. For example, implementation intentions—where individuals preplan "when" and "how" to achieve an emotion regulation goal, forming an "if-then" execution pattern that automatically executes when conditions are met (Gallo et al., 2007, 2009; Webb et al., 2012)—represent a transition from controlled to automatic processes. Additionally, changes in external feedback or contextual cues can cause certain habitually executed automatic processes to shift toward controlled processes (Hikosaka & Isoda, 2010).

Therefore, we argue it is necessary to separately classify implicit emotion regulation with dynamic execution process characteristics based on the multi-level framework' s dual classification. We term this "implicit goal-driven emotion regulation," with the most typical example being implicit goal pursuit, which often implicitly induces emotion regulation goals through priming to achieve unconscious emotion regulation.

As shown in Figure 1 [Figure 1: see original paper]B, this paper classifies implicit emotion regulation based on the degree of controlled processing into: automatic implicit emotion regulation (primarily automatic), task-incidental implicit emotion regulation (primarily controlled), and implicit goal-driven emotion regulation (dynamically variable).

Figure 1 Classification of implicit emotion regulation. A: Adapted from the multi-level framework of emotion regulation proposed by Gross, a leading scholar in the field, which divides implicit emotion regulation into "implicit automatic emotion regulation" and "implicit controlled emotion regulation" (Braunstein et al., 2017). B: The tripartite framework proposed in this paper, including "automatic implicit emotion regulation," "task-incidental implicit emotion regulation," and "implicit goal-driven emotion regulation."

3 Brain Imaging Findings on Implicit Emotion Regulation

Multiple neural models of emotion regulation (Dixon et al., 2017; Etkin et al., 2015; Ochsner et al., 2012; Phillips et al., 2008; Rive et al., 2013; Silvers & Guassi Moreira, 2019; Smith & Lane, 2015) propose that emotion regulation is achieved by modulating emotion-generating brain regions (such as the amygdala) via regulatory brain regions. Regulatory brain regions comprise cognitive control brain regions and automatic regulation brain regions. Cognitive control brain regions include the supplementary motor area, pre-supplementary motor area, and frontoparietal control network, which includes the dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), and parietal cortex. Automatic regulation brain regions include the ventral anterior cingulate cortex, ventromedial prefrontal cortex (VMPFC), hippocampus, and parahippocampal gyrus. Different implicit emotion regulation processes show varying dependence on cognitive control (Braunstein et al., 2017), suggesting diverse regulatory mechanisms and neural pathways. This section explores the cognitive and neural mechanisms of different implicit emotion regulation types in conjunction with brain imaging research.

3.1 Automatic Implicit Emotion Regulation

Automatic implicit emotion regulation does not depend on explicit regulation intention initiation or active processing; emotional change typically occurs during experiential learning and value updating (Braunstein et al., 2017; Etkin et al., 2015). Its characteristics and advantages lie in acting upon emotional processes without consuming cognitive resources, without requiring attentional or prefrontal cognitive control resources, thereby reducing potential conflicts with objective situations or subjective will, making emotion regulation occur more "naturally" with high adaptability, stability, and lasting regulatory effects. The drawback is the lack of conscious monitoring, making external manipulation difficult; when such regulation malfunctions, identification and intervention become challenging.

The most typical example is fear extinction, which refers to the gradual weakening or elimination of conditioned fear responses through repeated presentation of a conditioned stimulus (CS) without accompanying unconditioned stimuli (US) such as electric shocks or noise (Dunsmoor et al., 2015; Maren & Holmes, 2016; Zabik et al., 2023). During this process, individuals do not consciously manipulate their emotions, yet their emotional responses to the conditioned stimulus change (Velasco et al., 2019). The cognitive mechanism involves repeated exposure to previously fear-inducing cues in safe environments without harm, causing the initially learned "fear" association to gradually weaken and be replaced by new safety memories, resulting in significantly reduced emotional responses when encountering the same cues later. Fear extinction exhibits typical inhibitory learning characteristics. Rather than directly erasing original memory traces, extinction is thought to form a new memory that competes with the initial fear memory, with individuals learning that cues previously predicting threat no longer accompany danger in the current context. Thus, the post-extinction CS- "safety" association coexists with the original CS-US fear association and suppresses fear response expression under appropriate conditions (Kalisch et al., 2006). This inhibitory process operates at an implicit level without conscious participation.

Besides fear extinction, reinforcer revaluation also constitutes automatic implicit emotion regulation. This process indirectly changes emotional responses by altering the value of outcomes associated with stimuli. Common experimental paradigms include reinforcer devaluation and reinforcer inflation. In devaluation experiments, individuals first establish stimulus-outcome associations (e.g., CS-food), then reduce the affective value of the outcome (e.g., inducing satiety or aversion) to weaken responses to the original stimulus. In inflation paradigms, outcome salience is increased (e.g., stronger shocks, larger rewards) to enhance emotional responses. Although individuals do not actively regulate emotions, their responses to stimuli change due to outcome value updating (Bouton, 2024; Morrison & Salzman, 2010). Therefore, fear extinction and reinforcer revaluation represent two examples of automatic implicit emotion regulation, respectively exemplifying "deconditioning" of negative emotional responses and "recoding" of emotional value. This regulatory mechanism of habituation/adaptation to emotional stimuli through repeated exposure exists across species, is highly adaptive, and forms the core principle of clinical interventions such as exposure therapy (Herrmann et al., 2017).

Brain imaging research reveals that automatic implicit emotion regulation involves coordinated activity across multiple key brain regions, including the amygdala, hippocampus, and VMPFC. First, the amygdala plays a critical role in storing emotional representations and expressing emotions, such as storing CS-US associations during initial fear and reinforcer evaluation and driving physiological responses through downstream projections to the brainstem (Braunstein et al., 2017). During fear extinction, the amygdala also participates in learning new safety associations (Li et al., 2011). VMPFC regulates amygdala activity and updates stimulus emotional value (Motzkin et al., 2015; Roy et al., 2012). Numerous studies have found VMPFC activity increases during fear extinction (Cremers et al., 2021; Wik et al., 1997; Gottfried and Dolan, 2004; Phelps et al., 2004). For example, VMPFC plays an important role in consolidating and retrieving extinction memories, promoting retrieval of extinction (i.e., safety) memories when individuals re-encounter previous threat cues, thereby inhibiting amygdala fear responses and reducing fear experience, with VMPFC activation levels negatively correlating with amygdala response strength (Bukalo et al., 2015; Sotres-Bayon & Quirk, 2010). Unlike the amygdala, the hippocampus primarily provides context-related information to modulate emotional responses. During fear extinction, it encodes the environmental context where extinction occurs, making retrieval of safety memories context-dependent (Lonsdorf et al., 2014; Goode & Maren, 2019; Brown et al., 2025). When individuals are in the same context as extinction learning, hippocampal activation facilitates VMPFC recruitment of safety memory networks, successfully suppressing amygdala-initiated fear responses; but if the context changes, hippocampal encoding of the original context no longer matches, extinction memory retrieval is blocked, and amygdala expression of fear memory dominates again, causing fear response recovery (Kalisch et al., 2006). Empirical studies support this interactive model among brain regions: during extinction recall tests, VMPFC and hippocampus typically show positively correlated synchronous activation, with higher network activation levels predicting better fear inhibition effects. Conversely, fear recovery is observed with enhanced amygdala and hippocampus activity accompanied by decreased VMPFC activity (Zabik et al., 2023).

In summary, automatic implicit emotion regulation is a process that spontaneously changes emotional responses through repeated environmental exposure without conscious intervention or cognitive control resource investment. During this process, individuals do not actively regulate emotions, yet their emotional responses are effectively suppressed and maintained long-term, highlighting this regulation form' s advantages in adaptability, stability, and energy efficiency. From an evolutionary perspective, this mechanism represents the emotion system' s experience-driven fine-tuning capacity at the unconscious level. Therefore, automatic implicit emotion regulation is not only a low-cost regulation method but may also represent the fundamental form of the emotion system' s endogenous regulatory capacity, holding theoretical value for understanding the evolutionary basis of emotion regulation and designing clinical interventions.

3.2 Task-Incidental Implicit Emotion Regulation

In contrast to automatic regulation, task-incidental implicit emotion regulation depends on cognitive control, where emotion regulation implementation does not stem from specific regulation goals but rather incidentally produces emotional response changes through activation of top-down cognitive control during execution of other tasks (such as cognitive inhibition, conflict monitoring, or judgment operations). This "incidental emotion regulation" process is not primarily aimed at regulating emotions; instead, emotion regulation emerges as a byproduct of task execution, showing clear task-dependency and function-oriented characteristics (Lieberman et al., 2007).

Typical task-incidental implicit emotion regulation appears in affect labeling, emotional Stroop, and emotional Go/No-go tasks. In these paradigms, individuals' goals and tasks are not to actively regulate emotions but to complete cognitive tasks such as rapid responding, semantic judgment, or inhibiting irrelevant stimuli. For example, affect labeling tasks require participants to select a more appropriate word from two options to label the content of currently presented negative pictures—essentially putting a label on their current emotional experience. In these paradigms, emotional reactions carried by or accompanying the task are irrelevant to task goals but can interfere with task performance (e.g., disrupting semantic processing or inhibitory control). The top-down prefrontal cognitive control system activated by the task then incidentally regulates these interfering emotions. This regulation neither stems from conscious regulation intention nor directly aims to change emotions but rather, while ensuring smooth task completion, automatically suppresses or screens out interfering emotional information, achieving an adaptive process of resource optimization. From an adaptability perspective, when emotional stimuli interfere with cognitive tasks, the regulatory process is passively activated as an implicit resource management strategy, enabling rapid filtering and functional suppression of emotional input. Its essence lies in maintaining cognitive system stability and efficiency rather than directly changing emotional states.

Brain imaging studies have found that in paradigms such as emotional Stroop and emotional Go/No-go, individuals must focus on the task itself (e.g., ignoring emotional words while naming facial expressions or making button responses when seeing fearful faces). Although task goals do not involve emotion regulation intention, task execution activates cognitive control-related brain regions such as DLPFC and VLPFC, which incidentally regulate emotional response brain regions while completing cognitive tasks (Ochsner & Gross, 2005). Additionally, similar implicit emotion regulation effects appear in semantic judgment paradigms. For example, affect labeling tasks require individuals to select appropriate semantic labels (e.g., "fear") when viewing emotional faces. Although the task does not involve explicit emotion regulation goals, the label selection process itself activates cognitive control brain regions such as VLPFC, effectively inhibiting emotional responses, reducing amygdala activity, and decreasing subjective negative emotional experiences (Burklund et al., 2015; Cohen & Lieberman, 2010; Kerns et al., 2004; Payer et al., 2012; Townsend et al., 2013). Therefore, lateral prefrontal regions play an important role in this type of implicit emotion regulation.

In summary, when cognitive tasks contain emotion-interfering information irrelevant to task goals, the prefrontal cognitive control network activated by the task itself incidentally regulates emotional responses. This process both ensures smooth task completion and effectively changes emotional responses by inhibiting activity in emotion-generating brain regions such as the amygdala. This implicit regulatory mechanism emphasizes the resource optimization and functional suppression characteristics exhibited by the emotion system when serving higher-order cognitive goals.

3.3 Implicit Goal-Driven Emotion Regulation

Unlike the clearly automatic or controlled emotion regulation described above, implicit goal-driven emotion regulation demonstrates the potential for dynamic switching between reliance on cognitive control and automatic execution. The primary cognitive mechanism involved is the implementation of implicit goals. When emotion regulation goals are implicitly implanted or activated, they can unconsciously influence subsequent processing of emotional stimuli, promoting emotional responses to shift in a goal-consistent direction—a phenomenon known as implicit goal pursuit. In the goal dimension, implicit goal-driven emotion regulation differs from explicit controlled emotion regulation in that regulation goals shift from explicit to implicit (Gyurak et al., 2011; Mauss et al., 2007b). In the process dimension, the initiation and execution of goal-driven implicit emotion regulation do not depend on immediate conscious decision-making or continuous cognitive resource allocation, thus generating less cognitive load, while remaining manipulable through control of contextual factors, distinguishing it from fully automatic processes (Braunstein et al., 2017).

The most common method of implicit goal-driven regulation is priming to activate emotion regulation goals and induce implicit goal pursuit. For example, through sentence unscrambling tasks or word matching tasks that require participants to rearrange scrambled words into coherent sentences or select synonyms from two alternatives, individuals passively encounter and process regulation-related semantic cues (e.g., "stay calm" or "face positively") without explicit regulation intention, automatically activating corresponding regulation goals that induce subsequent emotion regulation. Additionally, implicit goal-driven emotion regulation can exert effects early in emotion generation. For instance, briefly priming regulation-related cues before emotional stimulus presentation produces altered neural responses during early emotion processing stages, such as significantly enhanced N170 component amplitude related to facial emotion processing (Liu et al., 2018) or reduced P1 component amplitude related to early attention (高可翔等, 2023). These findings indicate that implicit goal priming initiates regulatory processes before emotional responses are fully formed.

Implicit goal-driven emotion regulation can adjust emotional responses in a low cognitive load manner according to primed regulation goals, even without explicit intention. Series of brain imaging studies show this process involves both broad inhibition of emotion-processing brain regions and selective activation of regulation-related brain regions. For example, Zhang et al. (2020) used an emotion regulation semantic priming paradigm to examine socially acquired fear, finding that under implicit regulation conditions, activation in emotion-processing brain regions such as the amygdala significantly decreased, while executive control brain regions such as DLPFC and dorsal anterior cingulate cortex showed no significant activation enhancement, indicating that implicit regulation at this time does not require high cognitive-cost executive control. Furthermore, Xie et al. (2019) used a subliminal presentation paradigm of emotion regulation words, finding that even with implicit priming conditions of only

33 or 50 ms, emotion suppression words could reduce individuals' emotional responses to negative stimuli, with DLPFC and VLPFC activation significantly lower than in explicit regulation conditions, suggesting that implicit regulation can achieve effective modulation without substantially consuming cognitive resources. Wyczesany et al. (2021) found that when individuals unconsciously induced self-control or reappraisal goals, activation in emotion-processing brain regions such as visual cortex and amygdala triggered by negative emotional stimuli significantly decreased, indicating effective emotional response inhibition, while activity in cognitive control regions such as DLPFC increased, suggesting that implicit goals can also achieve emotion down-regulation through cognitive control pathways. Similarly, Wang et al. (2017) used a pre-description paradigm where a sentence reinterpreting negative picture content from a positive perspective was presented before each negative picture, implicitly inducing cognitive reappraisal of upcoming negative information without explicit regulation instructions. Results similarly found that compared to negative description conditions, implicit emotion regulation conditions activated regulatory brain regions such as DLPFC, accompanied by weakened amygdala activation and enhanced negative functional connectivity between prefrontal and limbic systems, confirming that implicit goals can also mobilize top-down regulatory pathways for emotion regulation. Likewise, Zhang et al. (2021) used forward and backward masking to present emotion regulation goal words for only 20 ms, finding DLPFC activation enhancement positively correlated with regulation effects. Moreover, after acute exercise enhanced DLPFC activation, repeating the above task further increased DLPFC activation. This phenomenon reflects that implicit regulatory mechanisms can flexibly adjust regulatory strategies according to dynamic changes in external environment and cognitive resources, achieving optimal emotion regulation effects at minimal cost across different contexts.

We propose that implicit goal-driven emotion regulation represents an emotion regulation mode that lies between the classic "cognitive control" and "automatic response" dichotomy (Braunstein et al., 2017). This mechanism reflects an adaptive balance optimization achieved by the emotion regulation system during evolution—under resource-limited environmental conditions, it can both maintain flexible responses to emotional stimuli and avoid high costs from continuous cognitive resource occupation, while showing high sensitivity to external contextual and internal resource state changes. This dynamic operating mode that combines "purposefulness" with "adaptability" not only expands our traditional understanding of emotion regulation theory but also reveals the core evolutionary advantage of the human emotion system in adapting to stressful environments and rapidly and effectively managing emotional responses in complex ecological contexts.

This section systematically reviews the cognitive and neural mechanisms of implicit emotion regulation, identifying key brain regions and neural pathways involved in automatic, task-incidental, and goal-driven implicit regulation. At the extreme, automatic implicit emotion regulation directly modulates the amygdala via VMPFC with almost no reliance on lateral prefrontal cognitive control functions, whereas task-incidental emotion regulation is directly regulated by lateral prefrontal regions (Etkin et al., 2015). Between these two types, implicit goal-driven emotion regulation may involve both regulatory mechanisms and may possess coordination or switching mechanisms yet to be discovered. A recent explicit emotion regulation study showed that controlled emotion regulation first activates DLPFC and VLPFC, which then recruit VMPFC, which subsequently modulates amygdala and other emotion brain region activity (He et al., 2023). Therefore, we propose that VMPFC may be a key brain region for implicit emotion regulation, participating in the three types of implicit emotion regulation and explicit emotion regulation through different cognitive processes and neural pathways. In addition to the brain imaging evidence mentioned in this section, neuromodulation evidence also supports our view.

4 Neuromodulation Findings on Implicit Emotion Regulation

While brain imaging research has elucidated activity patterns in brain networks accompanying implicit emotion regulation, how can we reveal which brain regions play causal roles in implicit emotion regulation? How can we effectively utilize these mechanisms clinically, for example, by modulating relevant brain region activity to improve patients' emotional symptoms? These are urgent questions requiring exploration.

4.1 Causal Brain Regions for Implicit Emotion Regulation

In the domain of automatic implicit emotion regulation, studies have used non-invasive neuromodulation techniques such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) to examine VMPFC' s core role in automatic implicit emotion regulation. For example, researchers combined fMRI and tDCS, finding that after VMPFC activation, the tDCS group showed significantly lower negative emotion intensity when viewing negative videos compared to the tDCS control group (Abend et al., 2019). Similarly, another study using the ultimatum game to induce anger found that after VMPFC activation, participants showed significantly reduced activity in emotional experience brain regions such as the anterior insula, increased acceptance rates of unfair proposals, and decreased subjective anger and aggressive behavior (Gilam et al., 2018). Moreover, anodal tDCS or high-frequency repetitive TMS activating VMPFC can significantly facilitate fear extinction (Lei et al., 2024; Marković et al., 2021). For instance, Van' t Wout et al. (2016, 2017) and Vicario et al. (2020) used anodal tDCS to activate VMPFC, observing enhanced fear extinction in both healthy participants and PTSD patients. Herrmann et al. (2017) applied high-frequency repetitive TMS (10 Hz) to VMPFC to activate this region, then used virtual reality exposure therapy to treat acrophobia. Results showed that compared to the TMS control group, the TMS group demonstrated significantly improved exposure therapy effects. Rodent studies similarly indicate that activating the functional homolog of VMPFC (infralimbic cortex) facilitates fear extinction (Marković et al., 2021). Beyond targeting VMPFC directly as an implicit emotion regulation target, some studies have attempted to modulate lateral cortical regions functionally connected to VMPFC, thereby producing connection-based indirect modulation effects on VMPFC to regulate emotional responses in the amygdala and other regions. For example, Raij et al. (2018) used 300 ms online TMS (20 Hz) to activate a specific left frontal cortex region during conditioned fear extinction that had been previously shown to have significant functional connectivity with VMPFC, finding that the TMS group showed enhanced fear extinction compared to the control group.

In the domain of task-incidental implicit emotion regulation, neuromodulation studies have found that even without explicit emotion regulation goals, activation of cognitive control brain regions can causally improve emotion regulation effects. For example, Cao et al. (2018) used continuous theta-burst stimulation (cTBS) to activate participants' right prefrontal cortex, finding that alpha power in response to positive emotional faces significantly decreased during emotional Go/No-go tasks. Since alpha frequency typically indicates cortical inhibition, this result suggests enhanced positive emotion in participants. Bermpohl et al. (2005, 2006) used low-frequency repetitive TMS to inhibit DLPFC, finding this manipulation disrupted behavioral control performance in emotional Go/No-go tasks, particularly when emotional information and task goals required rapid switching. Recently, Lapate et al. (2024) applied cTBS to lateral prefrontal cortex to inhibit its cognitive control functions, finding that task-incidental implicit emotion regulation effects weakened, with negative emotional cues causing significantly greater interference in No-go tasks.

In the domain of implicit goal-driven emotion regulation, neuromodulation studies have examined both automatic emotion regulation brain regions and cognitive control brain regions. 华艳等 (2020) found that after inhibiting the left orbitofrontal cortex via cathodal tDCS, the subsequent attentional avoidance effect induced by visual masked priming (20 ms priming word presentation) in a dot-probe task significantly weakened, indicating that orbitofrontal cortex has a causal role in attention allocation during this process. Another study used tDCS to activate VMPFC, finding that implicitly primed reappraisal effects induced by sentence unscrambling tasks significantly improved, with negative emotional responses markedly decreased (高可翔等, 2023; Gao et al., 2024). Similarly, Q. Zhang et al. (2023) used tDCS to activate right DLPFC and VLPFC, finding that implicit goal-driven emotion regulation induced by word matching tasks significantly enhanced regulation of negative emotions (both subjective ratings and electrophysiological indices).

Existing neuromodulation research indicates that VMPFC is at least a causal brain region for two types of implicit emotion regulation: in automatic implicit regulation, it can down-regulate amygdala emotional responses; in implicit goal-driven regulation, enhanced VMPFC excitability can significantly improve implicit reappraisal effects. Although no neuromodulation studies have directly examined VMPFC' s role in task-incidental implicit regulation, existing evidence shows that stimulating lateral prefrontal regions can indirectly modulate VMPFC through functional connectivity (Lynch et al., 2022; Oathes et al., 2021; Raij et al., 2018; Sydnor et al., 2022), and VMPFC also plays an important role in explicit emotion regulation (which similarly heavily depends on cognitive control) (Diekhof et al., 2011). Therefore, future research should further investigate VMPFC' s role in controlled implicit emotion regulation.

4.2 Challenges Facing Neuromodulation Techniques

Although we have identified VMPFC' s core role in implicit emotion regulation, using VMPFC as a non-invasive brain stimulation treatment target presents certain anatomical and technical limitations. First, VMPFC' s anatomical location poses challenges for effective modulation (Lopez-Persem et al., 2019; Mackey & Petrides, 2014). VMPFC is located deep within the brain. Due to current attenuation by brain tissue, the modulatory effects of non-invasive brain stimulation techniques on this region are generally weak (Drakaki et al., 2022; Saturnino et al., 2021). Additionally, since applying non-invasive brain stimulation inevitably involves (often stronger) electromagnetic stimulation to superficial lateral brain regions, this creates issues with focality of brain region targeting, reducing the strength of causal inferences about VMPFC from experimental findings. Multichannel direct current stimulation techniques and temporal interference technology may be promising approaches. The former improves stimulation focality while enhancing safety by shunting current intensity across each electrode pair pathway. For example, the aforementioned Q. Zhang et al. (2023) used multichannel tDCS technology to activate right DLPFC and VLPFC regions, finding enhanced implicit goal-driven emotion regulation effects; similarly, Gao et al. (2024) used focality-optimized multichannel tDCS to activate VMPFC in high trait anxiety individuals, improving implicit emotion regulation effects. Moreover, Sergiou et al. (2022) used small ring electrodes for high-precision tDCS activation of VMPFC, placing the anode on VMPFC with five return electrodes arranged in a circle around it, finding this operation significantly reduced violent behavior in violent offenders with substance dependence. No applications of temporal interference technology in emotion regulation research have been identified to date.

Overall, neuromodulation techniques show considerable application prospects in intervention research on implicit emotion regulation. However, existing neuromodulation techniques primarily target lateral prefrontal and other cortical surface regions (Qiu et al., 2023). Future research should optimize stimulation depth and targeting precision (in addition to electrical stimulation, ultrasound stimulation is also an emerging effective technique) to further clarify the cognitive and neural mechanisms of implicit emotion regulation and provide effective treatment protocols for clinical practice.

5 Implications of Implicit Emotion Regulation for Treating Depression and Anxiety

Depression and anxiety, as the two most common mood disorders, are characterized in part by abnormal emotion regulation (Gross & Jazaieri, 2014; Zilverstand et al., 2017). Depressed patients remain immersed in negative emotions long-term, exhibiting anhedonia (Joormann & Stanton, 2016; Liu & Thompson, 2017); anxiety patients remain in a state of high negative emotional arousal long-term, showing excessive sensitivity to stress (Elwood et al., 2012). Patients with depression and anxiety have difficulty down-regulating negative emotional experiences through explicit emotion regulation, particularly cognitive reappraisal (Heller et al., 2009; Urry et al., 2009). The main reasons for these patients' explicit emotion regulation difficulties lie in both impaired cognitive resources and executive control functions and damaged emotion regulation neural circuits with abnormal functional connectivity among emotion regulation brain regions (Park et al., 2019).

We therefore propose that the three types of implicit emotion regulation identified in this paper may offer advantages for depression and anxiety populations. First, automatic implicit regulation processes can reduce emotional responses without conscious participation, which is highly beneficial for alleviating excessive fear and physiological hyperarousal in anxiety patients; similarly, such automatic processes can relieve negative emotions in depressed patients without occupying prefrontal cognitive resources. Second, task-incidental implicit regulation occurs incidentally while individuals perform other cognitive tasks, making it suitable for depressed individuals with limited cognitive resources and insufficient regulation motivation. We can design appropriate task contexts to indirectly activate emotion regulation networks, achieving emotional improvement under unintentional conditions. Finally, we can unconsciously activate positive emotion regulation goals (e.g., subtly priming "positive reappraisal"), enabling emotion regulation strategies that are difficult to execute actively to operate implicitly.

5.1 Implications for Depression

Depressive symptoms (particularly persistent negative thinking) consume substantial cognitive resources, impairing patients' executive functions, memory, and attention (Joormann & Quinn, 2014; Quinn et al., 2018; Rock et al., 2014; Snyder, 2013; Vilgis et al., 2015). Depressed patients show insufficient lateral prefrontal activation and excessive amygdala activation during explicit down-regulation of negative emotions (Joormann & Stanton, 2016; Liu & Thompson, 2017). Reduced lateral prefrontal activation indicates cognitive control deficits, while amygdala hyperactivation reflects explicit emotion regulation failure (Zilverstand et al., 2017). Notably, one study simultaneously examined depressed patients' use of implicit and explicit emotion regulation to cope with frustration, finding that compared to healthy controls, patients' ability to improve negative emotions through explicit cognitive reappraisal (instructed to interpret current situations more positively) significantly decreased; however, when implicit cognitive reappraisal was induced through word matching tasks, this implicit goal-driven emotion regulation effect showed no significant difference from healthy controls (Yuan et al., 2022). Therefore, implicit emotion regulation offers new treatment avenues for depression: implicit emotion regulation types that consume fewer cognitive control resources and depend less on cognitive control functions (Mauss et al., 2007a; Yang et al., 2015; Yuan et al., 2019) may play important roles in depressed patients with limited cognitive resources.

5.2 Implications for Anxiety

Chronic hypervigilance in anxious individuals leads to impaired top-down control capabilities and insufficient cognitive resources. Control deficits make it difficult for patients to successfully implement explicit emotion regulation strategies such as cognitive reappraisal that consume cognitive resources (Calhoon & Tye, 2015; Ironside et al., 2019; Kenwood et al., 2022; Pruessner et al., 2020; Troy et al., 2018). Meanwhile, anxiety disorder patients exhibit dual characteristics of hyper-sensitive limbic systems related to emotional responses and weakened prefrontal regulatory brain region functions (Brandl et al., 2022; Brändle et al., 2020; Calhoon & Tye, 2015; Hiser & Koenigs, 2018). High trait anxiety individuals show slow emotional state recovery when performing emotional Go/No-go tasks, suggesting that anxiety may weaken cognitive control' s inhibitory and implicit regulation of emotions (Liu et al., 2018). Wang et al. (2021) found that panic disorder patients, unlike healthy controls, could not effectively reduce subjective negative emotions and amygdala activity when receiving positive suggestions before viewing negative pictures (implanting implicit emotion regulation goals). This failure of implicit emotion regulation positively correlated with insufficient activation of DLPFC and VLPFC. Similarly, generalized anxiety patients also showed reduced activation in orbitofrontal and other prefrontal regions during implicit goal pursuit induced by the same paradigm (Wang et al., 2024). These results suggest that anxiety disorders affect the normal functioning of executive control brain regions, making it difficult for patients to regulate emotional responses even at the implicit level.

We argue that this evidence does not deny the value of implicit emotion regulation but rather emphasizes that anxiety disorder treatment should further explore and refine strategies based on patients' neural and functional impairments. In most cases, implicit emotion regulation functions remain functional in anxiety disorder patients. For example, through implicit exposure, gradually allowing patients to unconsciously contact fear stimuli (e.g., presenting relevant cues without triggering strong subjective fear) can reduce patients' avoidance behaviors, achieving effects similar to desensitization exposure therapy (Oyarzún et al., 2018). Similarly, the aforementioned Gao et al. (2024) study found that in implicit cognitive reappraisal goal pursuit induced by sentence unscrambling tasks, high trait anxiety individuals could effectively use this implicit emotion regulation method to reduce negative emotions, with this process depending less on prefrontal cognitive control systems. Therefore, future research should focus on the specific mechanisms underlying impaired implicit emotion regulation functions in different anxiety disorder patients and develop targeted intervention strategies accordingly.

In summary, implicit emotion regulation shows tremendous potential in treating depression and anxiety and other resource-limited populations due to its low cognitive resource dependence and high adaptability. On one hand, neuromodulation techniques can directly target key brain regions for implicit regulation (such as VMPFC) for targeted intervention, improving regulatory brain regions' ability to modulate emotion-generating brain regions like the amygdala. On the other hand, we can utilize implicit training paradigms to internalize emotion regulation goals and strengthen patients' implicit regulation skills (Hopp et al., 2011; Y. Zhang et al., 2023). It is foreseeable that as exploration of implicit emotion regulation mechanisms and clinical applications continues, intervention strategies oriented toward implicit emotion regulation will provide novel ideas and opportunities for clinical treatment of depression and anxiety.

6 Summary and Outlook

In summary, as an important form of emotion regulation, implicit emotion regulation exhibits diverse cognitive and neural mechanisms and holds potential value for treating mood disorders such as depression and anxiety. Compared to explicit emotion regulation with obvious regulation intentions and requiring active effort, implicit emotion regulation demonstrates higher automaticity and lower cognitive load. We propose that implicit emotion regulation represents an adaptive optimization of the emotion system, reflecting a "natural and fluent" emotion management capacity formed during human evolution. Even without conscious intervention, emotional responses can be appropriately adjusted, thereby avoiding the high energy consumption of continuous high-intensity cognitive control and maintaining emotional stability and functional efficiency at all times. The main theoretical contribution of this paper is the proposed tripartite framework of implicit emotion regulation, which for the first time defines the category of implicit goal-driven emotion regulation. This type of implicit emotion regulation shows more flexible dependence on cognitive control, reflecting the dynamic adjustment capacity of emotion regulation processes. It should be noted that implicit emotion regulation also has limitations: due to its lack of conscious participation, individuals have difficulty actively detecting and immediately adjusting implicit processes. When implicit regulation mechanisms themselves exhibit defects or biases (e.g., automatically negative biased thinking), correction and intervention become relatively difficult. Therefore, during use or training, we should weigh the advantages and limitations of implicit emotion regulation and view it as a beneficial supplement to explicit emotion regulation, jointly helping us improve emotion regulation capacity and maintain mental health.

Future research in implicit emotion regulation has several directions worth exploring. First, at the theoretical level, we need to further reveal dynamic variation patterns in the two dimensions of regulation goals and execution processes. For example, if we control one dimension while changing the other, how will the cognitive and neural mechanisms of emotion regulation change? Can this generate new clinical intervention methods? Do extreme types within the same dimension exhibit competitive or synergistic relationships? How does switching between different types within the same dimension occur, and can it be manipulated? Do the same brain regions play identical roles across different emotion regulation types? For instance, does lateral prefrontal cortex function identically in explicit controlled and task-incidental implicit emotion regulation?

Second, given that implicit emotion regulation processes are rapid and involve multiple brain regions, employing multimodal brain imaging approaches will be an important direction. For example, combining fMRI with simultaneous EEG recording can obtain both high spatial and high temporal resolution data to dynamically map the neural mechanisms of implicit regulation. Additionally, neuromodulation techniques should be more integrated into research paradigms to selectively alter specific brain region excitability (e.g., enhancing VMPFC or inhibiting DLPFC activity) and observe effects on implicit regulation outcomes, directly testing the causal roles of these regions in implicit emotion regulation.

Third, exploring the applicability of implicit emotion regulation from a developmental perspective is needed. Existing research has focused primarily on healthy adults, while characteristics of implicit emotion regulation in different populations and special groups remain unclear. Therefore, future research should examine implicit emotion regulation effects in broader populations. For example, investigating implicit regulation's role in adolescent emotional fluctuations to reveal how developing brains use implicit emotion regulation to improve emotions, or exploring whether implicit emotion regulation can serve as a compensatory emotion regulation method for cognitive aging, helping and guiding older adults to maintain positive emotions.

Finally, developing simpler, more feasible emotion regulation treatment plans tailored to clinical populations is essential. Future research could explore personalized neuromodulation treatment protocols, such as targeting and modulating specific brain regions based on patients'brain imaging characteristics (e.g., implementing personalized brain stimulation to enhance implicit emotion regulation capacity in patients with low VMPFC function). Simultaneously, developing specialized implicit emotion regulation training paradigms is a worthwhile direction. How can certain emotion regulation strategies be efficiently internalized into automatic responses through short-term practice? Additionally, clinical research should examine broader populations beyond the depression and anxiety mentioned in this review, including post-traumatic stress disorder, bipolar disorder, autism spectrum disorder, etc., to explore whether patients'implicit emotion regulation functions exhibit special patterns or deficits and thereby contribute to optimizing clinical treatment.

高可翔, 张岳瑶, 李思瑾, 袁加锦, 李红, 张丹丹. (2023). 腹内侧前额叶在内隐认知重评中的因果

作用. 心理学报, 55(2), 210–223.

华艳, 李明霞, 王巧婷, 冯彩霞, 张晶. (2020). 左侧眶额皮层在自动情绪调节下注意选择中的作用: 来自经颅直流电刺激的证据. 心理学报, 52(9), 1048–1056.

莫李澄, 李宜伟, 张丹丹. (2024a). 社会疼痛情绪调节的认知神经机制: 现状及展望. 应用心理学, 30(1), 33–43.

莫李澄, 李思瑾, 张丹丹. (2024b). 社会疼痛情绪调节的神经机制. 心理科学, 47(3), 530–537.

莫李澄, 郭田友, 张岳瑶, 徐锋, 张丹丹 (2021). 激活右腹外侧前额叶提高抑郁症患者对社会疼痛的情绪调节能力: 一项 TMS 研究. 心理学报, 53(5), 494–504

张丹丹, 李思瑾. (2024). 情绪调节的神经环路及其在情绪障碍人群中的表现. 四川师范大学学报(自然科学版), 47(3), 285–293.

Abend, R., Sar-el, R., Gonen, T., Jalon, I., Vaisvaser, S., Bar-Haim, Y., & Hendler, T. (2019). Modulating emotional experience using electrical stimulation of the medial-prefrontal cortex: A preliminary tDCS-fMRI study. Neuromodulation, 22(8), 884-893. https://doi.org/10.1111/ner.12787

Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. Clinical Psychology Review, 30(2), 217-237. https://doi.org/10.1016/j.cpr.2009.11.004

Bermpohl, F., Fregni, F., Boggio, P. S., Thut, G., Northoff, G., Otachi, P. T., Rigonatti, S. P., Marcolin, M. A., & Pascual-Leone, A. (2005). Left prefrontal repetitive transcranial magnetic stimulation impairs performance in affective go/no-go task. Neuroreport, 16(6), 615-619. https://doi.org/10.1097/00001756-200504250-00020

Bermpohl, F., Fregni, F., Boggio, P. S., Thut, G., Northoff, G., Otachi, P. T. M., Rigonatti, S. P., Marcolin, M. A., & Pascual-Leone, A. (2006). Effect of low-frequency transcranial magnetic stimulation on an affective go/no-go task in patients with major depression: Role of stimulation site and depression severity. Psychiatry Research, 141(1), 1-13. https://doi.org/10.1016/j.psychres.2005.07.018

Bouton, M. E. (2024). Habit and persistence. Journal of the Experimental Analysis of Behavior, 121(1), 88-96. https://doi.org/10.1002/jeab.1101

Brandl, F., Weise, B., Mulej Bratec, S., Jassim, N., Hoffmann Ayala, D., Bertram, T., Ploner, M., & Sorg, C. (2022). Common and specific large-scale brain changes in major depressive disorder, anxiety disorders, and chronic pain: A transdiagnostic multimodal meta-analysis structural functional MRI studies. Neuropsychopharmacology, 47(5), 1071-1080. https://doi.org/10.1038/s41386-022-01271-y

Brändle, F., Wu, C. M., & Schulz, E. (2020). What are we curious about? Trends in Cognitive Sciences, 24(9), 685-687. https://doi.org/10.1016/j.tics.2020.05.010

Braunstein, L. M., Gross, J. J., & Ochsner, K. N. (2017). Explicit and implicit emotion regulation: A multi-level framework. Social Cognitive Affective Neuroscience, 12(10), https://doi.org/10.1093/scan/nsx096

Brown, E. C., Artigas, S. O., Elsner, S., Liu, L., & Park, S. Q. (2025). Utilizing rewards to dampen fear and its recovery. Scientific reports, 15(1), 17671. https://doi.org/10.1038/s41598-025-99758-3

Bukalo, O., Pinard, C. R., Silverstein, S., Brehm, C., Hartley, N. D., Whittle, N., Colacicco, G., Busch, E., Patel, S., Singewald, N., & Holmes, A. (2015). Prefrontal inputs to the amygdala instruct fear extinction memory formation. Science Advances, 1(6), e1500251. https://doi.org/10.1126/sciadv.1500251

Burklund, L. J., Craske, M. G., Taylor, S. E., & Lieberman, M. D. (2015). Altered emotion regulation capacity in social phobia as a function of comorbidity. Social Cognitive and Affective Neuroscience, 10(2), 199–208. https://doi.org/10.1093/scan/nsu058

Calhoon, G. G., & Tye, K. M. (2015). Resolving the neural circuits of anxiety. Nature Neuroscience, 18(10), 1394–1404. https://doi.org/10.1038/nn.4101

Cao, D., Li, Y., Niznikiewicz, M. A., Tang, Y., & Wang, J. (2018). The theta burst transcranial magnetic stimulation over the right PFC affects electroencephalogram oscillation during emotional processing. Progress in Neuro-Psychopharmacology Biological Psychiatry, https://doi.org/10.1016/j.pnpbp.2017.12.005

Cohen, J. R., & Lieberman, M. D. (2010). The common neural basis of exerting self-control in multiple domains. control society, mind, brain, https://doi.org/10.1093/acprof:oso/9780195391381.003.0008

Cremers, H., Keedy, S., & Coccaro, E. (2021). The development of an fMRI protocol to investigate vmPFC network functioning underlying generalization behavioral control. Psychiatry Research: Neuroimaging, 307, 111197. https://doi.org/10.1016/j.pscychresns.2020.111197

Custers, R., & Aarts, H. (2010). The unconscious will: How the pursuit of goals operates outside of conscious awareness. Science, 329(5987), 47–50. https://doi.org/10.1126/science.1188595

Dalton, S. D. P., Cooper, H., Jennings, B., & Cheeta, S. (2025). The empirical status of implicit emotion regulation in mood and anxiety disorders: A meta-analytic review. Journal of affective disorders, 380, 256–269. Advance online publication. https://doi.org/10.1016/j.jad.2025.03.118

Diekhof, E. K., Geier, K., Falkai, P., & Gruber, O. (2011). Fear is only as deep as the mind allows. A coordinate-based meta-analysis of neuroimaging studies on the regulation of negative affect. NeuroImage, 58(1), 275–285. https://doi.org/10.1016/j.neuroimage.2011.05.073

Dixon, M. L., Thiruchselvam, R., Todd, R., & Christoff, K. (2017). Emotion and the prefrontal cortex: An integrative review. Psychological Bulletin, 143(10), 1033–1081. https://doi.org/10.1037/bul0000096

Drakaki, M., Mathiesen, C., Siebner, H. R., Madsen, K., & Thielscher, A. (2022). Database of 25 validated coil models electric field simulations Brain Stimulation, 15(3), https://doi.org/10.1016/j.brs.2022.04.017

Dunsmoor, J. E., Niv, Y., Daw, N., & Phelps, E. A. (2015). Rethinking extinction. Neuron, 88(1), 47–63. https://doi.org/10.1016/j.neuron.2015.09.028

Elwood, L. S., Wolitzky-Taylor, K., & Olatunji, B. O. (2012). Measurement of anxious traits: A contemporary review synthesis. Anxiety, Stress Coping, 25(6), https://doi.org/10.1080/10615806.2011.582949

Etkin, A., Büchel, C., & Gross, J. J. (2015). The neural bases of emotion regulation. Nature Reviews Neuroscience, 16(11), 693–700. https://doi.org/10.1038/nrn4044

Ferri, J., Schmidt, J., Hajcak, G., & Canli, T. (2016). Emotion regulation and amygdala-precuneus connectivity: Focusing on attentional deployment. Cognitive, Affective & Behavioral Neuroscience, 16(6), 991–1002. https://doi.org/10.3758/s13415-016-0447-y

Gallo, I. S., & Gollwitzer, P. M. (2007). Implementation intentions: Control of fear despite cognitive load. Psicothema, 280–285.

Gallo, I. S., Keil, A., McCulloch, K. C., Rockstroh, B., & Gollwitzer, P. M. (2009). Strategic automation of emotion regulation. Journal of personality and social psychology, 96(1), 11. https://doi.org/10.1037/a0014577

Gao, K., Wong, A. B., Li, S., Zhang, Y., & Zhang, D. (2024). The ventromedial prefrontal cortex plays an important role in implicit emotion regulation: A focality-optimized multichannel tDCS study in anxiety individuals. Human Brain Mapping, 45(13), e26812. https://doi.org/10.1002/hbm.26812

Gao, W., Yan, X., & Yuan, J. (2022). Neural correlations between cognitive deficits and emotion regulation strategies: understanding emotion dysregulation in depression from the perspective of cognitive control and cognitive biases. Psychoradiology, 2(3), 86–99. https://doi.org/10.1093/psyrad/kkac014

Gilam, G., Abend, R., Gurevitch, G., Erdman, A., Baker, H., Ben-Zion, Z., & Hendler, T. (2018). Attenuating anger and aggression with neuromodulation of the vmPFC: A simultaneous tDCS-fMRI study. Cortex, 109, 156–170. https://doi.org/10.1016/j.cortex.2018.09.010

Goode, T. D., & Maren, S. (2019). Common neurocircuitry mediating drug and fear relapse in preclinical models. Psychopharmacology, 236(1), 415–437. https://doi.org/10.1007/s00213-018-5024-3

Gottfried, J. A., & Dolan, R. J. (2004). Human orbitofrontal cortex mediates extinction learning while accessing conditioned representations of value. Nature Neuroscience, 7(10), 1144–1152. https://doi.org/10.1038/nn1314

Gross, J. J. (2015). The extended process model of emotion regulation: Elaborations, applications, and future directions. Psychological Inquiry, 26(1), 130-137. https://doi.org/10.1080/1047840X.2015.989751

Gross, J. J., & Jazaieri, H. (2014). Emotion, emotion regulation, and psychopathology: An affective science perspective. Clinical Psychological Science, 2(4), 387-401. https://doi.org/10.1177/2167702614536164

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. Journal of Personality and Social Psychology, 85(2), 348-362. https://doi.org/10.1037/0022-3514.85.2.348

Gyurak, A., Gross, J. J., & Etkin, A. (2011). Explicit and implicit emotion regulation: A dual-process framework. Cognition and emotion, 25(3), 400-412. https://doi.org/10.1080/02699931003782614

He, Z., Li, S., Mo, L., Zheng, Z., Li, Y., Li, H., & Zhang, D. (2023). The VLPFC-engaged voluntary emotion regulation: Combined TMS-fMRI evidence for the neural circuit of cognitive reappraisal. Journal of Neuroscience, 43(34), 6046-6060. https://doi.org/10.1523/JNEUROSCI.1337-22.2023

Heller, A. S., Johnstone, T., Shackman, A. J., Light, S. N., Peterson, M. J., Kolden, G. G., Kalin, N. H., & Davidson, R. J. (2009). Reduced capacity to sustain positive emotion in major depression reflects diminished maintenance of fronto-striatal brain activation. Proceedings of the National Academy of Sciences of the United States of America, 106(52), 22445-22450. https://doi.org/10.1073/pnas.0910651106

Herrmann, M. J., Katzorke, A., Busch, Y., Gromer, D., Polak, T., Pauli, P., & Deckert, J. (2017). Medial prefrontal cortex stimulation accelerates therapy response of exposure therapy in acrophobia. Brain Stimulation, 10(2), 291-297. https://doi.org/10.1016/j.brs.2016.11.007

Hikosaka, O., & Isoda, M. (2010). Switching from automatic to controlled behavior: Cortico-basal ganglia mechanisms. Trends in Cognitive Sciences, 14(4), 154-161. https://doi.org/10.1016/j.tics.2010.01.006

Hiser, J., & Koenigs, M. (2018). Review the multifaceted role of the ventromedial prefrontal cortex in emotion, decision making, social cognition, and psychopathology. Biological Psychiatry, 83(8), 638-647. https://doi.org/10.1016/j.biopsych.2017.10.030

Hopp, H., Troy, A. S., & Mauss, I. B. (2011). The unconscious pursuit of emotion regulation: Implications for psychological health. Cognition and Emotion, 25(3), 532-545. https://doi.org/10.1080/02699931.2010.532606

Ironside, M., Browning, M., Ansari, T. L., Harvey, C. J., Sekyi-Djan, M. N., Bishop, S. J., Harmer, C. J., & O' Shea, J. (2019). Effect of prefrontal cortex stimulation on regulation of amygdala response to threat in individuals trait anxiety: randomized clinical trial. Psychiatry, 76(1), https://doi.org/10.1001/jamapsychiatry.2018.2172

Joormann, J., & Quinn, M. E. (2014). Cognitive processes and emotion regulation in depression. Depression and Anxiety, 31(4), 308–315. https://doi.org/10.1002/da.22264

Joormann, J., & Stanton, C. H. (2016). Examining emotion regulation in depression: A review and future directions. Behaviour Research and Therapy, 86, 35–49. https://doi.org/10.1016/j.brat.2016.07.007

Konrad, A. C., Miu, A. C., Trautmann, S., & Kanske, P. (2025). Neural correlates and plasticity of explicit emotion regulation following the experience of trauma. Frontiers in Behavioral Neuroscience, 19, 1523035. https://doi.org/10.3389/fnbeh.2025.1523035

Kalisch, R., Korenfeld, E., Stephan, K. E., Weiskopf, N., Seymour, B., & Dolan, R. J. (2006). Context-dependent human extinction memory is mediated by a ventromedial prefrontal and hippocampal network. Journal of Neuroscience, 26(37), 9503–9511. https://doi.org/10.1523/JNEUROSCI.2021-06.2006

Kenwood, M. M., Kalin, N. H., & Barbas, H. (2022). The prefrontal cortex, pathological anxiety, and anxiety disorders. Neuropsychopharmacology, 47(1), 260–275. https://doi.org/10.1038/s41386-021-01109-z

Kerns, J. G., Cohen, J. D., MacDonald III, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring adjustments control. Science, 303(5660), https://doi.org/10.1126/science.1089910

Koole, S. L., & Rothermund, K. (2011). "I feel better but I don' t know why" : The psychology of implicit emotion regulation. Cognition and Emotion, 25(3), 389–399. https://doi.org/10.1080/02699931.2010.550505

Koole, S. L., Webb, T. L., & Sheeran, P. L. (2015). Implicit emotion regulation: Feeling better without knowing why. Current Opinion in Psychology, 3, 6–10. https://doi.org/10.1016/j.copsyc.2014.12.027

Lapate, R. C., Heckner, M. K., Phan, A. T., Tambini, A., & D' Esposito, M. (2024). Information-based TMS to mid-lateral prefrontal cortex disrupts action goals during emotional processing. Nature Communications, 15(1). https://doi.org/10.1038/s41467-024-48015-8

Lei, L., Lai, C. S., Lee, T. M., & Lam, C. L. (2024). The effect of transcranial direct current and magnetic stimulation on fear extinction and return of fear: A meta-analysis and systematic review. Journal of Affective Disorders, 362, 263-286. https://doi.org/10.1016/j.jad.2024.06.060

Li, Y., Li, S., Li, H., Tang, Y., & Zhang, D. (2025). fNIRS neurofeedback facilitates emotion regulation: Exploring individual differences ventrolateral prefrontal cortex. NeuroImage, 121079.https://doi.org/10.1016/j.neuroimage.2025.121079

Li, S., Chen, J., Gao, K., Xu, F., & Zhang, D. (2023). Excitatory brain stimulation over the left dorsolateral prefrontal cortex enhances voluntary distraction in depressed patients. Psychological Medicine, 53(14), 6646-6655.https://doi.org/10.1017/S0033291723000028

Li, S., Cao, X., Li, Y., Tang, Y., Cheng, S., & Zhang, D. (2024). Enhancing ventrolateral prefrontal cortex activation mitigates social pain and modifies subsequent social attitudes: Insights from TMS and fMRI. NeuroImage, 120620. https://doi.org/10.1016/j.neuroimage.2024.120620

Li, J., Schiller, D., Schoenbaum, G., Phelps, E. A., & Daw, N. D. (2011). Differential roles of human striatum and amygdala in associative learning. Nature Neuroscience, 14(10), 1250–1252. https://doi.org/10.1038/nn.2904

Lieberman, M. D., Eisenberger, N. I., Crockett, M. J., Tom, S. M., Pfeifer, J. H., & Way, B. M. (2007). Putting feelings in to words. Psychological Science, 18(5), 421–428. https://doi.org/10.1111/j.1467-9280.2007.01916.x

Lincoln, T. M., Schulze, L., & Renneberg, B. (2022). The role of emotion regulation in the characterization, development treatment psychopathology. Nature Reviews Psychology, 1(5), https://doi.org/10.1038/s44159-022-00040-4

Liu, B., Wang, Y., & Li, X. (2018). Implicit emotion regulation deficits in trait anxiety: An ERP study. Frontiers in Human Neuroscience, 12, 382. https://doi.org/10.3389/fnhum.2018.00382

Liu, D. Y., & Thompson, R. J. (2017). Selection and implementation of emotion regulation strategies in major depressive disorder: An integrative review. Clinical Psychology Review, 57(10), https://doi.org/10.1016/j.cpr.2017.07.004

Lonsdorf, T. B., Haaker, J., & Kalisch, R. (2014). Long-term expression of human contextual fear and extinction memories involves amygdala, hippocampus and ventromedial prefrontal cortex: A reinstatement study in two independent samples. Social cognitive affective neuroscience, 9(12), https://doi.org/10.1093/scan/nsu018

Lopez-Persem, A., Verhagen, L., Amiez, C., Petrides, M., & Sallet, J. (2019). The human ventromedial prefrontal cortex: Sulcal morphology and its influence on functional organization. Journal of Neuroscience, 39(19), https://doi.org/10.1523/JNEUROSCI.2060-18.2019

Lynch, C. J., Elbau, I. G., Ng, T. H., Wolk, D., Zhu, S., Ayaz, A., Power, J. D., Zebley, B., Gunning, F. M., & Liston, C. (2022). Automated optimization of TMS coil placement for personalized functional network engagement. Neuron, 110(20), 3263-3277.e4. https://doi.org/10.1016/j.neuron.2022.08.012

Mackey, S., & Petrides, M. (2014). Architecture and morphology of the human ventromedial prefrontal cortex. European Journal of Neuroscience, 40(5), 2777–2796. https://doi.org/10.1111/ejn.12654

Marković, V., Vicario, C. M., Yavari, F., Salehinejad, M. A., & Nitsche, M.

A. (2021). A systematic review on the effect of transcranial direct current and magnetic stimulation on fear memory and extinction. Frontiers in Human Neuroscience, 15, 655947. https://doi.org/10.3389/fnhum.2021.655947

Maren, S., & Holmes, A. (2016). Stress and fear extinction. Neuropsychopharmacology, 41(1), 58–79. https://doi.org/10.1038/npp.2015.180

Mauss, I. B., Bunge, S. A., & Gross, J. J. (2007a). Automatic emotion regulation. Social and Personality Psychology Compass, 1(1), 146-167. https://doi.org/10.1111/j.1751-9004.2007.00015.x

Mauss, I. B., Cook, C. L., & Gross, J. J. (2007b). Automatic emotion regulation during anger provocation. Journal of Experimental Social Psychology, 43(5), 698–711. https://doi.org/10.1016/j.jesp.2006.07.003

Morrison, S. E., & Salzman, C. D. (2010). Re-valuing the amygdala. Current Opinion in Neurobiology, 20(2), https://doi.org/10.1016/j.conb.2010.03.004

Motzkin, J. C., Philippi, C. L., Wolf, R. C., Baskaya, M. K., & Koenigs, M. (2015). Ventromedial prefrontal cortex is critical for the regulation of amygdala activity in humans. Biological Psychiatry, 77(3), 276–284. https://doi.org/10.1016/j.biopsych.2014.02.014

Oathes, D. J., Zimmerman, J. P., Duprat, R., Japp, S. S., Scully, M., Rosenberg, B. M., Flounders, M. W., Long, H., Deluisi, J. A., Elliott, M., Shandler, G., Shinohara, R. T., & Linn, K. A. (2021). Resting fMRI-guided TMS results in subcortical and brain network modulation indexed by interleaved TMS/fMRI. Experimental Brain Research, 239(4), 1165–1178. https://doi.org/10.1007/s00221-021-06036-5

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. Trends in Cognitive Sciences, 9(5), 242–249. https://doi.org/10.1016/j.tics.2005.03.010

Ochsner, K. N., Silvers, J. A., & Buhle, J. T. (2012). Functional imaging studies of emotion regulation: A synthetic review and evolving model of the cognitive control of emotion. Annals of the New York Academy of Sciences, 1251(1), E1-E24. https://doi.org/10.1111/j.1749-6632.2012.06751.x

Oyarzún, J. P., Càmara, E., Kouider, S., Fuentemilla, L., & de Diego-Balaguer, R. (2019). Implicit but not explicit extinction to threat-conditioned stimulus prevents spontaneous recovery of threat-potentiated startle responses in humans. Brain and behavior, 9(1), e01157. https://doi.org/10.1002/brb3.1157

Park, C., Rosenblat, J. D., Lee, Y., Pan, Z., Cao, B., Iacobucci, M., & Mcintyre, R. S. (2019). The neural systems of emotion regulation and abnormalities in major depressive disorder. Behavioural Brain Research, 367(4), 181–188. https://doi.org/10.1016/j.bbr.2019.04.002

Payer, D. E., Baicy, K., Lieberman, M. D., & London, E. D. (2012). Overlapping neural substrates between intentional incidental down-regulation negative emotions. Emotion, 12(2), https://doi.org/10.1037/a0027421

Phelps, E. A., Delgado, M. R., Nearing, K. I., & LeDoux, J. E. (2004). Extinction learning in humans: Role of the amygdala and vmPFC. Neuron, 43, 897-905. https://doi.org/10.1016/j.neuron.2004.08.031

Phillips, M. L., Ladouceur, C., & Drevets, W. C. (2008). Automatic and volontary regulation of emotion. Molecular Psychiatry, 13(9), 829-857. https://doi.org/10.1038/mp.2008.65.

Pruessner, L., Barnow, S., Holt, D. V, Joormann, J., & Schulze, K. (2020). A cognitive control framework for understanding emotion regulation flexibility. Emotion, 20(1), 21-29. https://doi.org/10.1037/emo0000658

Qiu, X., He, Z., Cao, X., & Zhang, D. (2023). Transcranial magnetic stimulation and transcranial direct current stimulation affect explicit but not implicit emotion regulation: A meta-analysis. Behavioral and Brain Functions, 19(1), 15. https://doi.org/10.1186/s12993-023-00217-8

Quinn, M. E., Stange, J. P., Jenkins, L. M., Corwin, S., DelDonno, S. R., Bessette, K. L., Welsh, R. C., & Langenecker, S. A. (2018). Cognitive control and network disruption in remitted depression: A correlate of childhood adversity. Social Cognitive Affective Neuroscience, 13(10), https://doi.org/10.1093/scan/nsy077

Raij, T., Nummenmaa, A., Marin, M. F., Porter, D., Furtak, S., Setsompop, K., & Milad, M. R. (2018). Prefrontal cortex stimulation enhances fear extinction memory in humans. Biological Psychiatry, 84(2), 129-137. https://doi.org/10.1016/j.biopsych.2017.10.022

Rive, M. M., Van Rooijen, G., Veltman, D. J., Phillips, M. L., Schene, A. H., & Ruhé, H. G. (2013). Neural correlates of dysfunctional emotion regulation in major depressive disorder. A systematic review of neuroimaging studies. Neuroscience & Biobehavioral Reviews, 37(10), 2529-2553. https://doi.org/10.1016/j.neubiorev.2013.07.018

Rock, P. L., Roiser, J. P., Riedel, W. J., & Blackwell, A. D. (2014). Cognitive impairment in depression: A systematic review meta-analysis. Psychological Medicine, 44(10), https://doi.org/10.1017/S0033291713002535

Roy, M., Shohamy, D., & Wager, T. D. (2012). Ventromedial prefrontal-subcortical systems and the generation of affective meaning. Trends in Cognitive Sciences, 16(3), 147-156. https://doi.org/10.1016/j.tics.2012.01.005

Saturnino, G. B., Madsen, K. H., & Thielscher, A. (2021). Optimizing the electric field strength in multiple targets for multichannel transcranial electric stimulation. Journal of Neural Engineering, 18(1). https://doi.org/10.1088/1741-2552/abca15

Sergiou, C. S., Santarnecchi, E., Romanella, S. M., Wieser, M. J., Franken, I. H. A., Rassin, E. G. C., & van Dongen, J. D. M. (2022). Transcranial direct current stimulation targeting the ventromedial prefrontal cortex reduces reactive aggression and modulates electrophysiological responses in a forensic population. Biological Psychiatry: Cognitive Neuroscience Neuroimaging, 7(1), https://doi.org/10.1016/j.bpsc.2021.05.007

Silvers, J. A., & Moreira, J. F. G. (2019). Capacity and tendency: A neuroscientific framework for the study of emotion regulation. Neuroscience Letters, 693, 35-39. https://doi.org/10.1016/j.neulet.2017.09.017

Smith, R., & Lane, R. D. (2015). The neural basis of one' s own conscious and unconscious emotional states. Neuroscience and Biobehavioral Reviews, 57, 1-29. https://doi.org/10.1016/j.neubiorev.2015.08.003

Snyder, H. R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive function: A meta-analysis and review. Psychological Bulletin, 139(1), 81-132. https://doi.org/10.1037/a0028727

Sotres-Bayon, F., & Quirk, G. J. (2010). Prefrontal control of fear: More than just extinction. Current Opinion in Neurobiology, 20(2), 231-235. https://doi.org/10.1016/j.conb.2010.02.005

Sydnor, V. J., Cieslak, M., Duprat, R., Deluisi, J., Flounders, M. W., Long, H., Scully, M., Balderston, N. L., Sheline, Y. I., Bassett, D. S., Satterthwaite, T. D., & Oathes, D. J. (2022). Cortical-subcortical structural connections support transcranial magnetic stimulation engagement of the amygdala. Science Advances, 8(25), 1-14. https://doi.org/10.1126/sciadv.abn5803

Tang, Y., Mo, L., Peng, Z., Li, Y., & Zhang, D. (2025). Causal enhancement of cognitive reappraisal through synchronized dorsolateral and ventrolateral prefrontal cortex activity. Emotion. Advance online publication. https://doi.org/10.1037/emo0001507

Townsend, J. D., Torrisi, S. J., Lieberman, M. D., Sugar, C. A., Bookheimer, S. Y., & Altshuler, L. L. (2013). Frontal-amygdala connectivity alterations during emotion downregulation in bipolar disorder. Biological Psychiatry, 73(2), 127-135. https://doi.org/10.1016/j.biopsych.2012.06.030

Troy, A. S., Shallcross, A. J., Brunner, A., Friedman, R., & Jones, M. C. (2018). Cognitive reappraisal and acceptance: Effects on emotion, physiology, and perceived cognitive costs. Emotion, 18(1), 58-74. https://doi.org/10.1037/emo0000371

Urry, H. L., van Reekum, C. M., Johnstone, T., & Davidson, R. J. (2009). Individual differences in some (but not all) medial prefrontal regions reflect cognitive demand while regulating unpleasant emotion. NeuroImage, 47(3), 852-863. https://doi.org/10.1016/j.neuroimage.2009.05.069

Van' t Wout, M., Mariano, T. Y., Garnaat, S. L., Reddy, M. K., Rasmussen, S. A., & Greenberg, B. D. (2016). Can transcranial direct current stimulation augment extinction of conditioned fear? Brain Stimulation. 9, 529-536. https://doi.org/10.1016/j.brs.2016.03.004

Van' t Wout, M., Longo, S. M., Reddy, M. K., Philip, N. S., Bowker, M. T., and Greenberg, B. D. (2017). Transcranial direct current stimulation may modulate extinction memory in posttraumatic stress disorder. Brain Behavior. 7(5), e00681. https://doi.org/10.1002/brb3.681

Velasco, E. R., Florido, A., Milad, M. R., & Andero, R. (2019). Sex differences in fear extinction. Neuroscience and Biobehavioral Reviews, 103 (11), 81–108. https://doi.org/10.1016/j.neubiorev.2019.05.020

Vicario, C. M., Salehinejad, M.A., Avenanti, A., Nitsche, M.A., 2020. Transcranial direct current stimulation (tDCS) in anxiety disorders. Non Invasive Brain Stimulation in Psychiatry and Clinical Neurosciences.

Vilgis, V., Silk, T. J., & Vance, A. (2015). Executive function and attention in children and adolescents with depressive disorders: A systematic review. European Child & Adolescent Psychiatry, 24(4), 365–384. https://doi.org/10.1007/s00787-015-0675-7

Wang, H. Y., Xu, G. Q., Ni, M. F., Zhang, C. H., Sun, X. P., Chang, Y., & Zhang, B. W. (2017). Neural mechanisms of implicit cognitive reappraisal: Preceding descriptions alter emotional response to unpleasant images. Neuroscience, 347, 65–75. https://doi.org/10.1016/j.neuroscience.2017.01.047

Wang, HY., Xu, GQ., Ni, MF. et al. Neural basis of implicit cognitive reappraisal in panic disorder: An event-related study. Journal Translational Medicine, 19(1), https://doi.org/10.1186/s12967-021-02968-2

Wang, H. Y., You, H. L., Song, C. L., Zhou, L., Wang, S. Y., Li, X. L., Liang, Z. H., & Zhang, B. W. (2024). Shared and distinct prefrontal cortex alterations of implicit emotion regulation in depression and anxiety: An fNIRS investigation. Journal of Affective Disorders, 354, 126–135. https://doi.org/10.1016/j.jad.2024.03.032

Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: a meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. Psychological Bulletin, 138(4), 775–808. https://doi.org/10.1037/a0027600

Wik, G., Elbert, T., Fredrikson, M., Hoke, M., & Ross, B. (1997). Magnetic brain imaging of extinction processes human classical conditioning. Neuroreport, https://doi.org/10.1097/00001756-199705060-00044

Williams, L. E., Bargh, J. A, Nocera, C. C., & Gray, J. R. (2009). The unconscious regulation: Nonconscious reappraisal goals modulate emotional reactivity. Emotion, 9(6), 847–854. https://doi.org/10.1037/a0017745

Wyczesany, M., Adamczyk, A. K., Ligeza, T. S., Bereś, A., & Marchewka, A. (2021). Implicit induction of emotional control—A comparative fMRI investigation of self-control and reappraisal goal pursuit. Emotion, 21(7), 1379–1391. https://doi.org/10.1037/emo0000852

Xie, Y., Hu, Z., Ma, W., Sang, B., & Wang, M. (2019). Different neural correlates of automatic emotion regulation at implicit and explicit perceptual level: A functional magnetic resonance imaging study. I-Perception, 10(1). https://doi.org/10.1177/2041669519831028

Yang, Q., Tang, P., Gu, R., Luo, W., & Luo, Y. (2015). Implicit emotion regulation affects outcome evaluation. Social Cognitive and Affective Neuroscience, 10(6), 824–831. https://doi.org/10.1093/scan/nsu124

Yuan, J., Long, Q., Li, X., Deng, Z., Ma, B., Chen, S., & Yang, J. (2019). Regulatory effect of implicit acceptance during outcome evaluation: The temporal dynamics in an event-related potential study. International Journal of Psychophysiology, 141(5), 37–44. https://doi.org/10.1016/j.ijpsycho.2019.05.003

Yuan, J., Zhang, Y., Zhao, Y., Gao, K., Tan, S., & Zhang, D. (2022). The Emotion-regulation benefits of implicit reappraisal in clinical depression: Behavioral and electrophysiological evidence. Neuroscience Bulletin. https://doi.org/10.1007/s12264-022-00973-z

Zabik, N. L., Peters, C., Iadipaolo, A., Marusak, H. A., & Rabinak, C. A. (2023). Comparison of behavioral and brain indices of fear renewal during a standard vs. novel immersive reality pavlovian fear extinction paradigm in healthy adults. Behavioural Brain Research, 437. https://doi.org/10.1016/j.bbr.2022.114154

Zhang, Q., Chen, T., Liu, S., Liu, X., Zhang, Y., Yu, F., Ji, G. J., Li, X., & Zhu, C. (2023). Effects of high-definition transcranial direct current stimulation on implicit emotion regulation of social pain in healthy individuals. Journal of Affective Disorders, 338, 74–82. https://doi.org/10.1016/j.jad.2023.05.075

Zhang, Y., Chen, S., Deng, Z., Yang, J., & Yuan, J. (2020). Benefits of implicit regulation of instructed fear: evidence from neuroimaging and functional connectivity. Frontiers in Neuroscience, 14(4), 1–13. https://doi.org/10.3389/fnins.2020.00201

Zhang, Y., Li, S., Gao, K., Li, Y., Yuan, J., & Zhang, D. (2023). Implicit, but not explicit, emotion regulation relieves unpleasant neural responses evoked by high-intensity negative images. Neuroscience Bulletin, 39(8), 1278–1288. https://doi.org/10.1007/s12264-023-01036-7

Zhang, Y., Shi, W., Wang, H., Liu, M., & Tang, D. (2021). The impact of acute exercise on implicit cognitive reappraisal in association with left dorsolateral prefronta activation: A fNIRS study. Behavioural Brain Research, 406(2). https://doi.org/10.1016/j.bbr.2021.113233

Zhu, C., Li, P., Li, Y., Jiang, Y., Liu, D., & Luo, W. (2022). Implicit emotion regulation improves arithmetic performance: An ERP study. Cognitive, Affective and Behavioral Neuroscience, 22(3), 574–585. https://doi.org/10.3758/s13415-021-00979-6

Zilverstand, A., Parvaz, M. A., & Goldstein, R. Z. (2017). Neuroimaging cognitive reappraisal in clinical populations to define neural targets for enhancing emotion regulation. A systematic review. NeuroImage, 151, 105–116. https://doi.org/10.1016/j.neuroimage.2016.06.009

The cognitive and neural mechanisms of implicit emotion regulation

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Abstract: Implicit emotion regulation refers to the process of modifying emotional responses without conscious monitoring or deliberate intention. Compared to explicit emotion regulation, implicit emotion regulation shows less dependence on the prefrontal executive control system. Building on existing dual-classification frameworks, this paper proposes a novel tripartite classification of implicit emotion regulation: automatic, task-incidental, and implicit goal-driven regulation. Automatic implicit regulation, exemplified by fear extinction, relies on the ventromedial prefrontal cortex (VMPC) directly modulating the amygdala. Task-incidental regulation occurs during tasks such as affect labeling and emotional Stroop, where lateral prefrontal regions incidentally regulate emotions through cognitive control systems during task execution. Implicit goal-driven regulation activates automatic emotion regulation goals through priming or implicit training, which can either utilize VMFC for automatic regulation or recruit lateral prefrontal cognitive control under certain conditions. Neuromodulation studies confirm that VMFC is a crucial causal region for implicit emotion regulation, and enhancing its function shows promise for improving implicit emotion regulation capacity in depression and anxiety patients. The proposed tripartite framework highlights the diverse mechanisms of implicit emotion regulation, extends the dynamic understanding of emotion regulation theory, and provides promising new avenues for clinical interventions in mood disorders.

Key words: emotion regulation, implicit emotion regulation, depression, anxiety, neuromodulation

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