


ORIGINAL ARTICLE

Neurophysiological mechanisms underlying the influence of motivational intensity on emotion regulation choice

Xinyu Yan^{1,2,3} | Wei Gao¹ | Jiemin Yang¹ | Salvatore Campanella⁴ | Jiajin Yuan^{1,5} 

¹The Laboratory for Affect Cognition and Regulation (ACRLAB), Institute of Brain and Psychological Sciences, Sichuan Normal University, Chengdu, China

²Psychologie, Sciences de l'Éducation et Logopédie, Université Libre de Bruxelles (ULB), Brussels, Belgium

³Faculty of Psychology, Southwest University, Chongqing, China

⁴Laboratory of Medical Psychology and Addictions, CHU Brugmann, ULB Neuroscience Institute (UNI), Université Libre de Bruxelles (ULB), Brussels, Belgium

⁵Sichuan Key Laboratory of Psychology and Behavior of Discipline Inspection and Supervision, Sichuan Normal University, Chengdu, China

Correspondence

Jiajin Yuan, Sichuan Key Laboratory of Psychology and Behavior of Discipline Inspection and Supervision, Institute of Brain and Psychological Sciences, Sichuan Normal University, Chengdu 610066, China.
Email: yuanjiajin168@126.com

Funding information

Science Fund for Distinguished Young Scholars of Sichuan Province, Grant/Award Number: 2023NSFSC1938; National Natural Science Foundation of China, Grant/Award Number: 31871103 and 31971018; Chinese Scholarship Council Grant, Grant/Award Number: 202407650041

Abstract

Motivation is considered a crucial factor in determining emotion regulation choice (ER choice). Our previous study revealed that increased motivation led to a preference for distraction over reappraisal due to the narrowed attention, yet neural underpinnings supporting this phenomenon remain unclear. In this study, we used event-related potentials (ERPs) to investigate whether motivation influences ER choice by early attention processing (P2) or late resource engagement (LPP). EEG activities were recorded for the pictorial contexts varying in motivational intensity and direction, while participants ($N=68$) were required to decide which strategy from the two options they would use to regulate their emotions. Consistent with previous studies, the results indicated that individuals chose more distraction over reappraisal in high-withdrawal motivated contexts while a reversed pattern was observed in low-withdrawal motivated contexts. Moreover, high-intensity motivated emotional contexts result in enhanced P2 and LPP. Further analysis indicates that only frontal P2 and the early LPP mediate the effect of motivational intensity on ER choice. These findings suggest that heightened motivation leads to a preference for distraction over reappraisal during emotion regulation due to the greater occupation of attentional resources.

KEYWORDS

distraction, emotion regulation choice, event-related potentials, motivational intensity, reappraisal

1 | INTRODUCTION

Emotion regulation choice (ER choice) refers to individuals' decisions on how to regulate their emotions in a given context when multiple strategies are active

(Sheppes, 2014). Considering that the adaptiveness of a certain strategy is not inherent but depends on the context, ER choice has been recognized as a crucial factor in mental health (Aldao et al., 2010; Kuo et al., 2018). Distraction and cognitive reappraisal are two common emotion regulation

strategies that received extensive investigation (e.g., Shafir et al., 2015; Sheppes & Meiran, 2007; Yang et al., 2021). Recent theories suggest that distraction and reappraisal occur at different stages of emotional processing, which leads to their adaptability changing with emotional contexts. This is a crucial factor that influences an individual's ER choice (Sheppes et al., 2011; Thiruchselvam et al., 2011). Namely, distraction involves replacing existing emotional information with independent neutral information and blocks incoming emotional processing. Thus, distraction occurs at the early stage of emotional processing. By contrast, reappraisal happens at the late stage, which involves developing neutral reinterpretations of emotional stimuli via semantic analysis (Moodie et al., 2020; Sheppes et al., 2011). Although emotional intensity has been identified as a robust determinant of ER choice in the past decade (e.g., Moyal et al., 2023; Sheppes et al., 2011), little is known about how the motivational attributes of emotion impact individual's choices.

Motivation is considered an emotional dimension independent of arousal and valence (Gable & Harmon-Jones, 2010b; Harmon-Jones, 2019), impacting individuals' information processing (Koch et al., 2008) and subsequent behaviors (Livermore et al., 2021). According to the motivational dimension model of emotion, the intensity of motivation refers to the strength of the urge to respond to a stimulus, and the motivational direction stresses whether this action is to approach or avoid the stimulus (Gable & Harmon-Jones, 2010b). Our recent study (Yang et al., 2021) revealed that increased motivation promotes distraction over reappraisal during ER, irrespective of motivational direction (approach or avoidance). However, the neural mechanism underlying this effect remains unclear, necessitating further investigation.

Notably, motivational intensity plays a crucial role in the processing of information at both early selective attention and late sustained elaboration (Dieterich et al., 2016; Hammerschmidt et al., 2017). Event-related potential (ERP) technology, with high temporal resolution, facilitates the examination of these effects. P2 is a positive deflection around 180 ms after stimulus onset (Kappenman & Luck, 2011), indicating rapid attention capture by emotional stimuli (Carretié et al., 2013; Schindler & Bublatzky, 2020). Studies have shown that stimuli activating intense motives attract more selective attention during early information processing, leading to enhanced anterior and posterior P2 amplitudes (Bublatzky & Schupp, 2012; Carretié et al., 2001; Schindler & Bublatzky, 2020). For instance, increased avoidance motivation elicited by uncertain cues heightens P2 amplitudes when individuals process subsequent images (Dieterich et al., 2016). Similarly, greater P2 responses are elicited by rewarding stimuli inducing high-approach motivation compared to

non-rewarding stimuli (Flores et al., 2015). More importantly, P2 is associated with affective evaluation (Kanske, Plitschka, & Kotz, 2011; Kappenman & Luck, 2011). In emotional contexts, such rapid appraisal of emotional information is crucial for determining how and whether one should act or react.

Aside from the influence on early attention, high-intensity motivated emotional stimuli also occupy more cognitive resources at the late stage of information processing (Gable & Adams, 2013). The late positive potential (LPP) is a centro-parietal slow wave starting around 300 ms after stimulus onset (Cuthbert et al., 2000; Schupp et al., 2000), reflecting the interaction of bottom-up attention allocation and top-down sustained elaboration with stronger top-down influence as stimulus processing progresses (Foti & Hajcak, 2008; Hajcak & Foti, 2020). LPP is modulated by motivational demands of affective contents (Schupp & Kirmse, 2021; Thom et al., 2014) and nonaffective tasks (Gable & Adams, 2013; Matsuda & Nittono, 2015), with greater positivity for motivationally salient stimuli like emotional pictures or motivation-related target. Moreover, the time course of the LPP has been shown to offer critical insight into affective processing, as it tracks an individual's sustained responsiveness to emotional stimuli over time. For example, previous studies (Weinberg & Hajcak, 2010) found that emotional stimuli accompanied by intense approach motivation (e.g., erotic stimuli) elicit greater early LPPs (400–1000 ms) compared to affiliative and exciting stimuli, while such an effect did not last in the later LPP (1000–1500 ms). A recent study also found that the LPP response failed to differentiate between negative and neutral pictures by middle LPP latency range (800–1000 ms) following happy incidental state priming (Hill et al., 2019). Together, these findings consistently support that motivation operates at both the early and late stages of emotional processing, as reflected by the modulation of P2 and LPP, respectively.

Given that it is a complex process involving bottom-up and top-down cognitive processing to decide on regulatory strategies (Hendricks & Buchanan, 2016; Kanske, Plitschka, & Kotz, 2011), while distraction and reappraisal act in different phases of emotion processing, we infer that the motivational intensity might influence individual's strategy selection by impacting both P2 and LPP. To test this assumption, the current study employed an emotion regulation choice task (Milyavsky et al., 2019; Sheppes et al., 2014), where participants select between distraction and reappraisal to regulate emotions evoked by images varying in motivational intensity and direction. Previous studies show that the neural signals induced by stimulus cues can effectively predict individuals' preferences in the following decision-making behavior (Barnett & Cerf, 2017; Hakim et al., 2023). Therefore, the aim of

this study was to examine the potential mediation of specific neural processes by which motivational intensity affects ER choice. To this end, a mediation analysis was conducted to investigate the underlying mechanisms of such psychological processes. Specifically, we focus on P2 and LPP, indicative of early attention and late elaboration, respectively. This analysis would help to provide a more comprehensive understanding of how motivation impacts emotion regulation choice.

Overall, we expected that the motivational intensity activated by emotional stimuli would impact an individual's emotion regulation choice between distraction and reappraisal. Consistent with previous findings (Yang et al., 2021), participants would prefer distraction in high-intensity motivated emotional contexts, and choose reappraisal more frequently when faced with low-intensity motivated situations. Based on previous studies (Martín et al., 2013; Shafir et al., 2016), we assume that the motivational intensity could modulate brain activity related to early attention and late sustained elaboration, which in turn predict individuals' subsequent strategy choices. Particularly, the increased P2 and LPP evoked by high-versus low-intensity motivated stimuli would be associated with distraction preference over reappraisal.

2 | METHODS

2.1 | Participants

Sixty-eight¹ undergraduate students (45 women; $M_{\text{age}} = 20.34$, $SD = 1.33$) were recruited from the local university through physical handouts within university premises and posters on online platforms, such as QQ, WeChat, and BaiduTieba. They were compensated with 90~100 yuan after completing the experiment. All the participants were right-handed with normal or corrected vision and reported no history of mental disorder or substance use (for details see Table 1). Data from 10 participants were excluded due to excessive electrophysiological artifacts, resulting in behavioral data analysis for 68

¹Sample size was determined with reference to the ERP studies on the motivational dimension of affect and emotion regulation choice (e.g., Liu et al., 2014; Shafir et al., 2016). Using WebPower Online (Zhang & Yuan, 2018; link: <https://webpower.psychstat.org>), we conducted a priori power analysis to ensure sufficient sample size for detecting the effect in a two-factor repeated measures ANOVA.

According to WebPower Online, a minimum sample size of 58 participants is required to detect a significant main effect of motivational intensity with a partial η^2 of 0.16 ($f = 0.43$), to achieve a power of 0.8 ($1 - \beta$) with the number of groups set 1, number of measurements set 4. Thus, we reasoned that a sample of 68 would be sufficient to examine our assumption.

participants and EEG data analysis for 58 participants. All participants signed consent forms, in line with the ethical principles issued by the ethics committee of human research at Southwest University.

2.2 | Stimuli

One hundred sixty pictures² selected from the IAPS (Lang et al., 2008), OASIS (Kurdi et al., 2017), and the internet were used to induce different emotions varying in motivational intensity (high vs. low) and direction (approach vs. avoidance). Another 20 university students (14 women; $M_{\text{age}} = 23.50$, $SD = 1.54$) who came from the same university as the experiment sample and did not participate in the formal experiment were recruited to rate arousal (1 = *low*, 9 = *high*), valence (1 = *very unpleasant*, 9 = *very pleasant*) and motivation (1 = *very eager to avoidance*, 9 = *very eager to approach*). Specifically, high-approach-motivated pictures ($N = 40$, $M_{\text{valence}} = 6.61 \pm 0.47$, $M_{\text{arousal}} = 7.12 \pm 0.25$) and low-approach-motivated pictures ($N = 40$, $M_{\text{valence}} = 6.57 \pm 0.41$, $M_{\text{arousal}} = 7.06 \pm 0.28$) were not significantly different in valence and arousal ratings; the same pattern was also recorded in the withdrawal-motivated emotional stimuli. In the motivational rating, we subtracted 5 from the raw score to obtain a new score. The sign of this new score represented the motivational direction (plus: approach; minus: withdrawal), while the absolute value reflected the intensity of motivation, with a larger score indicating a stronger motive to either approach or avoid the stimulus. Significant differences in motivational intensity and direction were observed among the four picture categories, as detailed in Table 2.

2.3 | Procedure

Emotion regulation choice task (Sheppes, 2020) was conducted in this study to test participants' preference for strategies in different motivational contexts. Before the formal experiment, participants learned the instructions and practiced how to implement distraction and reappraisal. Distraction instruction mainly entails the disengagement from emotional stimuli by generating unrelated, neutral thoughts. Reappraisal instruction involves engaging attention to the current context and reinterpreting it in a non-emotional or constructive way (Shafir et al., 2015; Yang et al., 2021). Participants then completed an eight-trial practice, consisting of four distraction and four reappraisal

²Selected picture numbers from IAPS and OASIS were presented in the supplementary materials. All the stimulus pictures and their subjective ratings can be found in the OFS.

TABLE 1 Demographic and psychological characteristics of the subjects and their correlations.

| | M (SD) | Min | Max | 3 | 4 | 5 | 6 |
|-------------------------------|--------------|-----|-----|----------|---------|---------|------|
| 1. Age | 20.07 (2.59) | 18 | 24 | | | | |
| 2. Sex(male/female) | 23/45 | | | | | | |
| 3. Depression ^a | 6.99 (7.51) | 0 | 28 | - | | | |
| 4. Trait anxiety ^b | 41.07 (9.64) | 21 | 62 | 0.75*** | - | | |
| 5. State anxiety ^b | 39.14 (9.40) | 21 | 61 | 0.66*** | 0.87*** | - | |
| 6. Reappraisal ^c | 31.15 (4.17) | 20 | 40 | -0.322** | -0.39** | -0.43** | - |
| 7. Suppression ^c | 15.69 (4.05) | 6 | 23 | 0.10 | 0.19 | 0.20 | 0.11 |

Abbreviation: SD, standard deviation.

** $p < .01$. *** $p < .001$.

^aDepression was measured by Beck Depression Inventory-II(BDI-II, Beck, 1996), and the individuals with a total score over 28 are regarded severe depression.

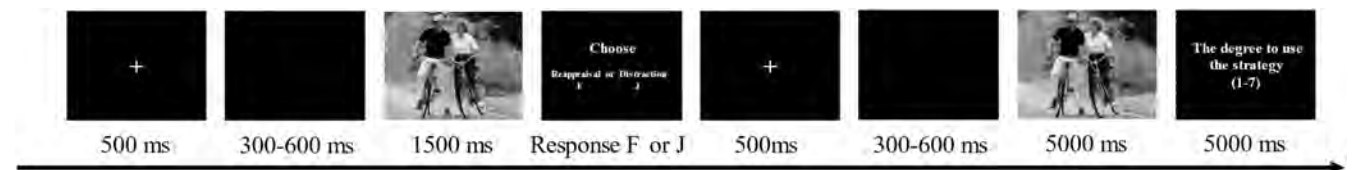
^bTrait and state anxiety were measured by the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983).

^cThe habitual use of reappraisal and suppression was assessed by the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003).

TABLE 2 Valence, arousal, and motivation of selected emotional stimuli M (SD).

| Direction | Valence | | | Arousal | | | Motivation | | |
|-----------|------------|------------|----------|------------|------------|----------|------------|-------------|----------|
| | Approach | Withdrawal | <i>t</i> | Approach | Withdrawal | <i>t</i> | Approach | Withdrawal | <i>t</i> |
| High | 6.61 (.47) | 2.69 (.43) | 32.92*** | 7.12 (.25) | 7.28 (.45) | -3.36** | 2.05 (.41) | -2.56 (.41) | -5.83*** |
| Low | 6.57 (.42) | 2.75 (.27) | 48.73*** | 7.06 (.28) | 7.18 (.35) | -3.40** | 1.39 (.10) | -1.26 (.15) | 3.36** |
| <i>t</i> | .33 | -1.99 | | 1.00 | 1.57 | | 29.82*** | 50.43*** | |

** $p < .01$. *** $p < .001$.


FIGURE 1 The schematic illustration of emotion regulation choice task.

trials across different motivational conditions. The order of strategy presentation was randomized. To ensure comprehension of the instructions, participants verbally reported how they implemented distraction and reappraisal, with corrections provided by the experimenter if necessary.

Following the practice session, the formal experiment including 160 trials started. The experimental protocol for each trial is illustrated in Figure 1. Each trial began with the presentation of a fixation for 500 ms, followed by a black blank screen with 300-600 ms. Subsequently, an emotional image was presented for 1500 ms. Participants were then instructed to freely select either the “Distraction” or “Reappraisal” by pressing the corresponding buttons (“F” or “J”). If no response occurred within 5 s, the next trial commenced. The assignment of strategies to buttons was counterbalanced. Participants were then required to regulate their emotions using the chosen strategy with the picture presentation for 5000 ms. Finally, they rated the extent to which they utilized the selected strategy for

emotion regulation on a 1 (not at all) to 7 (very much) scale. A 30-s rest was allotted between every 20 trials. To confirm the emotional attributes of the used pictures and minimize the influence of emotion regulation on the ratings, participants rated the valence, arousal, and motivation of all images 1 week after the experiment.

As in the previous study (Yang et al., 2021), we calculate the percentage of the trials in which the reappraisal strategy was chosen (POR) in each condition and participant, indexing the emotion regulation preference for reappraisal. A higher percentage indicates a greater tendency to choose reappraisal, while a lower percentage indicates a stronger preference for distraction.

2.4 | EEG recording and analysis

Continuous EEG recordings were performed by a 64-electrode head cap (Brain Products) according to the

standard international 10–20 system (sampling rate: 1000 Hz; band-pass: 0.01–100 Hz, notch filter: 50 Hz). The ground electrode was positioned on the media frontal line between Fz and FPz. FCz was selected as the online reference. All the electrode impedance was kept below 5 k Ω .

Offline EEG pre-processing was conducted with MATLAB (vision2019b) and EEGLAB toolbox v2021.0. Firstly, the continuous EEG was filtered offline using a basic FIR filter with a 0.1–40 Hz band-pass implemented in EEGLAB and was downsampled at 500 Hz. Nonbrain electrodes were removed and artifactual channels were rejected using the `clean_raw` data plugin in EEGLAB (1 participant was excluded due to more than 50% bad channels). The EEG data was then re-referenced to the average activity of bilateral mastoids (TP9, TP10). Subsequently, the continuous data was segmented into epochs for the entire duration (1500 ms) of the picture's initial presentation with a baseline correction of 300 ms pre-picture period. Through the `reject_data_epochs` function, epochs with amplitudes exceeding $\pm 85 \mu\text{V}$ were rejected, resulting in 154 ± 7 epochs per subject (for further details see Table S1; 8 subjects were excluded due to the presence of fewer than 75% valid epochs, while one subject was excluded due to the presence of fewer than 50% valid epochs in low-intensity withdrawal conditions; Luck, 2014). Eye blinks, and horizontal and vertical saccadic eye movements were removed from the segmented waveforms using the independent component analysis (ICA) by the `runica` plugin ("binica" function) in EEGLAB. Eye-movement-related ICA components were marked by visual inspection and removed from the data. Finally, the EEG epochs were averaged for the four different emotional conditions separately.

In previous studies, the P2 component has been observed to occur approximately 200 ms after the presentation of a stimulus at both the frontal and posterior areas (Kanske, Heissler, et al., 2011; Yuan et al., 2007). The LPP effect has been found to be the most pronounced in the parietal-occipital region (Hajcak & Dennis, 2009; Liu et al., 2012). Thus, based on these studies and the topographic characteristics observed in the present experiment, the P2 component was scored as the mean activity in 170–220 ms after the onset of stimuli at the midline sites from the frontal to parietal regions (Fz, Cz, Pz), respectively. The LPP was calculated as the mean activity in 300–1500 ms across parietal-occipital sites (Pz, P1, P2, POz, PO3, PO4). Previous studies suggested that different time windows of LPP may capture distinct phases of emotion responding, reflecting variations in how emotions are processed over time (e.g., Huang et al., 2023; Schindler & Straube, 2020; Weinberg & Hajcak, 2011).

To more precisely investigate the impact of emotional information processing on strategy selection in this study, we averaged the waveforms across high- and low-withdrawal-motivated emotional conditions (Luck & Gaspelin, 2017). Based on this analysis, as well as visual inspection of the data, we divided the LPP into three distinct subcomponents: an early stage (300–500 ms), a middle stage (500–1000 ms), and a late stage (1000–1500 ms).

Furthermore, for all ERP components utilized in statistical comparisons, we reported the standardized measurement error (SME, Luck et al., 2021) as a data quality measure (see Table S1).

2.5 | Statistical analysis

Behavioral and ERP data was statistically analyzed by the IBM SPSS Statistics software version 21.0 (IBM, New York, NY, USA). Descriptive data was presented as mean \pm SD. Repeated-measure analysis of variance (ANOVA) was performed on POR, P2, and LPP amplitudes to examine the effect of motivational intensity and direction. The Greenhouse–Geisser correction was applied when the assumption of sphericity was violated. Post hoc multiple comparisons were conducted using the Bonferroni–Holm test when significant main or interaction effects were observed. The significance level was at .05 and partial η -square was also reported as a measure of effect size for the ANOVA results.

To further test the relationships between behavioral data and ERP indicators in this within-subject experiment, we used the method proposed by Nunez Castellar et al. (2010), which was developed and verified in our recent study (Yang et al., 2021). Specifically, we calculated the POR and ERP indicators for each participant in each condition, respectively. Thus, we have four values of POR, and four values of each ERP indicator for each participant, which enables us to obtain a regression coefficient per participant ($\beta_1, \beta_2, \dots, \beta_n$). This process was performed on MATLAB and based on the `fitfm` plugins. Finally, we could test whether the beta coefficients of all participants were significantly different from zero for overall participants.

2.6 | Transparency and openness

We report how we determined our sample size, data exclusions, manipulations, and measures in the study. All data, analysis code, and research materials are available at <https://osf.io/y6qnh/>. This study's design and its analysis were not pre-registered.

3 | RESULTS

3.1 | Manipulated test

The post-experiment emotion ratings validated the successful manipulation of approach versus withdrawal motivation as well as high versus low motivation (see Figure 2a). Additionally, the arousal ratings for all emotional picture types significantly exceeded 5 (the midpoint of the scale, $p_s < .01$). Moreover, the valence ratings for high- and low-withdrawal motivational stimuli were both significantly below 5 ($p_s < .01$), whereas the ratings for both types of approach motivational stimuli surpassed 5 ($p_s < .01$), thereby confirming that the pictures used in this study were emotionally evocative.

3.2 | Behavioral results

A two-factor repeated measures ANOVA on POR revealed a significant main effect of motivational intensity, $F(1,67) = 25.19$, $p < .001$, $\eta_p^2 = .27$, and an interaction between motivational intensity and direction, $F(1, 67) = 11.08$, $p = .001$, $\eta_p^2 = .14$. Overall, participants demonstrated a greater tendency to select reappraisal as the regulatory strategy in low-intensity motivated contexts (0.63 ± 0.20) than in high-intensity motivated contexts (0.55 ± 0.18 ; $d = 0.08$, $p < .001$, 95% CI [0.05, 0.11]). Specifically, there was a higher proportion of reappraisal in low-withdrawal (0.65 ± 0.23) than in high-withdrawal motivated contexts (0.52 ± 0.24 ; $d = 0.13$, $p < .001$, 95% CI [0.08, 0.19]), whereas this difference was not significant between high-versus low-approach motivated contexts (high-approach: 0.59 ± 0.26 ; low-approach: 0.61 ± 0.23 ; $d = 0.02$, $p = .12$, 95% CI [-0.01, 0.05]). However, there was no significant effect of motivational direction, $F(1,67) = 0.12$, $p = .74$, $\eta_p^2 = .02$. For more details, please see Figure 2b.

3.3 | ERP results

3.3.1 | P2

Figure 3a presents the topographies of P2 in different emotional contexts. The 2 (motivational intensity: high vs. low) \times 2 (motivational direction: approach vs. withdrawal) \times 3 (location: Fz vs. Cz vs. Pz) repeated-measures ANOVA demonstrated a significant three-way interaction among motivational intensity, motivational direction and location, $F(1,57) = 5.81$, $p = .01$, $\eta_p^2 = .09$. Further analysis revealed a significant interaction between motivational intensity and direction at the Pz site, $F(1, 57) = 6.08$, $p = .02$, $\eta_p^2 = .10$. Specifically, stimuli with high-approach motivation elicited larger P2 amplitudes ($3.89 \pm 0.53 \mu\text{V}$) compared to low-approach motivated stimuli ($2.41 \pm 0.60 \mu\text{V}$, $d = 1.49$, $p < .001$, 95% [0.93, 2.05]). However, no significant differences were observed between high- and low-withdrawal motivated stimuli at Pz (high-withdrawal: $2.15 \pm 0.60 \mu\text{V}$, low-withdrawal: $1.77 \pm 0.61 \mu\text{V}$; $d = 0.38$, $p = .34$, 95% [-0.41, 1.17]).

In contrast, the interaction between motivational intensity and direction was not significant at the Cz and Fz sites [Fz: $F(1,57) = 0.32$, $p = .57$, $\eta_p^2 < .01$; Cz: $F(1,57) = 0.31$, $p = .58$, $\eta_p^2 < .01$] while the main effects of intensity and direction were significant at Fz [Intensity: $F(1,57) = 22.08$, $p < .001$, $\eta_p^2 = .28$; Direction: $F(1,57) = 54.81$, $p < .001$, $\eta_p^2 = .49$] and Cz [Intensity: $F(1,57) = 31.77$, $p < .001$, $\eta_p^2 = .36$; Direction: $F(1,57) = 49.35$, $p < .001$, $\eta_p^2 = .46$]. Namely, high-intensity motivated stimuli evoked greater P2 than low-intensity motivated stimuli, and enhanced P2 was observed at approach-motivated conditions compared to withdrawal-motivated conditions at these two electrodes. Besides, there is a significant main effect of location [$F(1,57) = 154.51$, $p < .001$, $\eta_p^2 = .73$], suggesting P2 amplitude was largest at Pz while the smallest at Fz. More details are shown in Figure 3b-d.

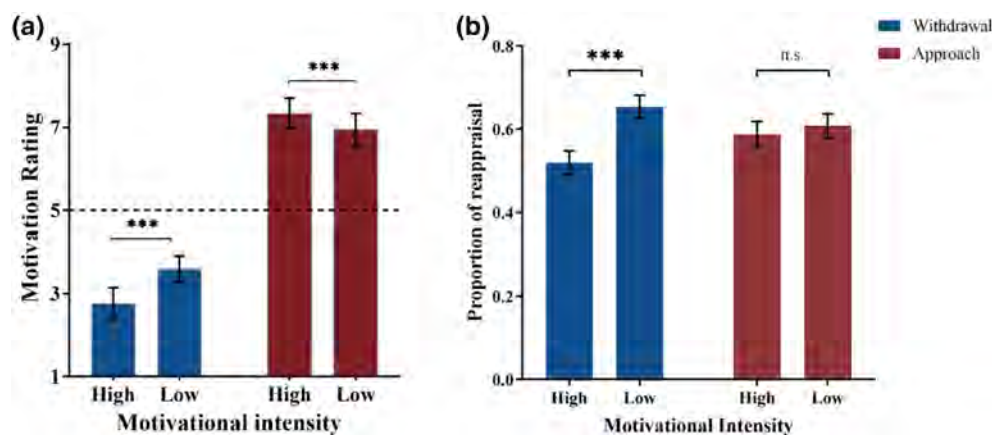


FIGURE 2 (a) Participants' motivational ratings for the emotional images; (b) the emotion regulation choice in different emotional contexts. *** $p < .001$, n.s. = no significance.

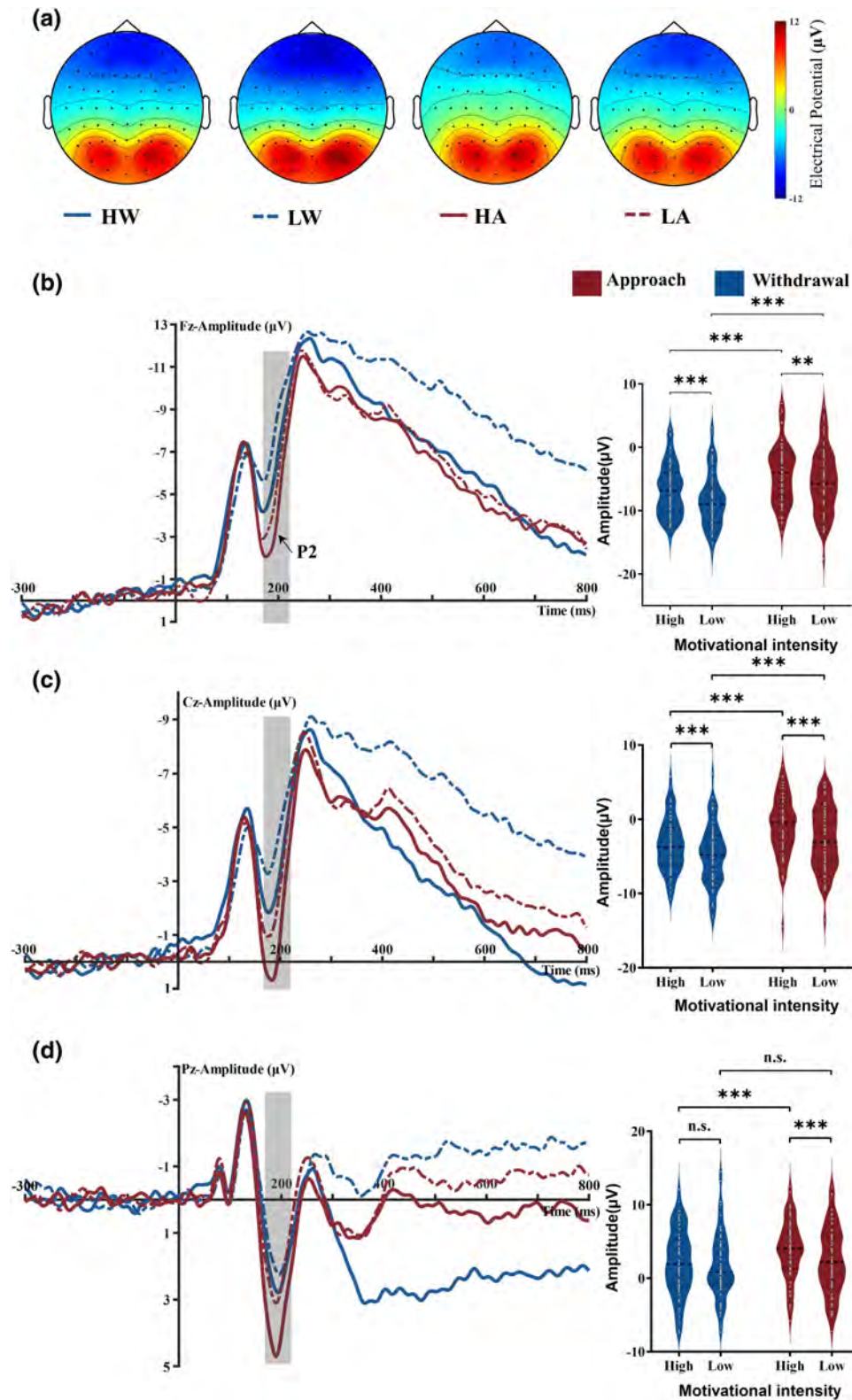


FIGURE 3 The P2. (a) the topographies of P2 (averaged across a time window of 170- 220 ms) in different emotional conditions; (b)–(d) the waveforms and amplitudes at Fz, Cz, and Pz sites, respectively. ** $p < 0.01$, *** $p < 0.001$, n.s.=no significance.

3.3.2 | LPP (300–1500 ms)

Figure 4a and b present the grand average ERP waveforms at the parietal-occipital electrode sites and the

topographies at three different time windows. The three-way repeated-measures ANOVA with motivational intensity, direction, and time window (early, middle, and late) as independent variables indicated

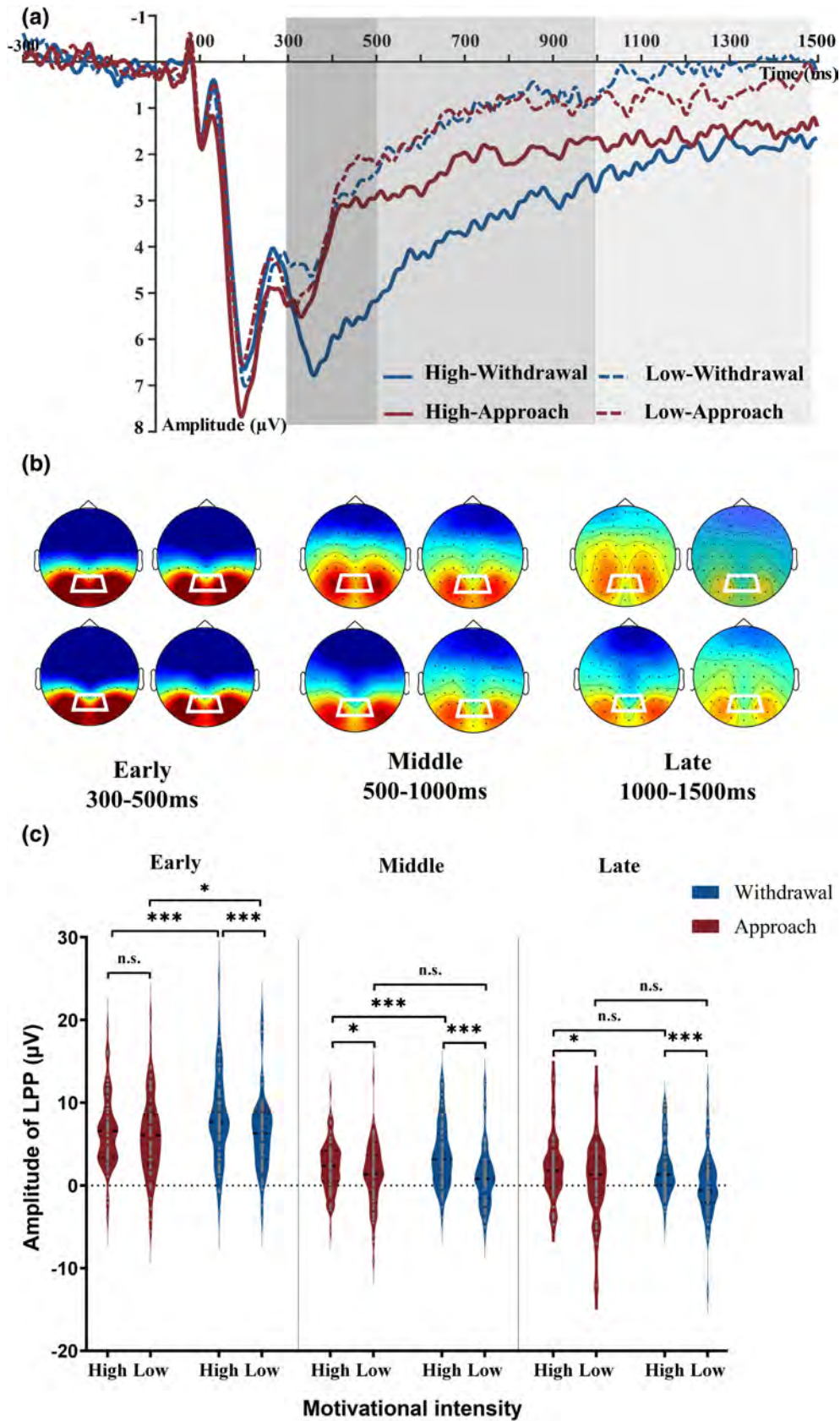


FIGURE 4 The late positive potential (LPP). (a) the waveforms (averaged across electrodes Pz, P1, P2, POz, PO3, and PO4) of LPP; (b) topographies of LPP in three time windows; (c) the amplitudes of the LPP evoked by emotional stimuli varying motivational intensity and direction in three time windows. * $p < .05$, *** $p < .001$, n.s.=no significance.

significant main effects of intensity [$F(1,57) = 30.03$, $p < .001$, $\eta_p^2 = .35$] and direction [$F(1,57) = 5.17$, $p = .03$, $\eta_p^2 = .08$]. The high-intensity motivated stimuli elicited significantly greater LPPs ($4.13 \pm 0.45 \mu\text{V}$) than low-intensity motivated stimuli ($2.64 \pm 0.50 \mu\text{V}$, $d = 1.49$, $p < .001$, 95% CI [0.95, 2.04]); and larger LPPs were observed in withdrawal-motivated emotional conditions ($3.63 \pm 0.48 \mu\text{V}$) compared to approach-motivated emotional conditions ($3.11 \pm 0.44 \mu\text{V}$, $d = 0.54$, $p = .03$, 95% CI [0.07, 1.02]). The main effect of the time window was significant, $F(1, 57) = 150.59$, $p < .001$, $\eta_p^2 = .73$, with the LPP gradually attenuating over time. For more details, please see Figure 4c.

Furthermore, the interaction between motivational intensity and direction was significant, $F(1, 57) = 7.52$, $p < .01$, $\eta_p^2 = .12$. High-withdrawal motivated stimuli evoked greater LPP ($4.71 \pm 0.52 \mu\text{V}$) than high-approach motivated stimuli ($3.56 \pm 0.44 \mu\text{V}$, $d = 1.15$, $p < .01$, 95% CI [0.48, 1.82]), but this effect disappeared between low-withdrawal (2.61 ± 0.63) versus low-approach motivated stimuli ($2.67 \pm 0.52 \mu\text{V}$, $d = -.06$, $p = .31$, 95% CI [-0.69, 0.57]).

We also found a significant interaction between motivational intensity and time window, $F(1, 57) = 4.66$, $p = .02$, $\eta_p^2 = .08$. High-intensity motivated stimuli elicited a more pronounced LPP than low-intensity motivated stimuli across three time windows ($ps < .001$). The difference was largest in the middle phase (500–1000 ms) and smallest in the early phase (300–500 ms).

Finally, a significant interaction between direction and time window was observed, $F(1, 57) = 16.56$, $p < .001$, $\eta_p^2 = .23$. Specifically, greater LPPs were recorded in withdrawal-motivated emotional conditions compared to approach-motivated conditions in the early (withdrawal: $7.37 \pm 0.67 \mu\text{V}$; approach: $6.27 \pm 0.62 \mu\text{V}$; $d = 1.11$, $p < .001$, 95% CI [0.58, 1.66]) and middle phases (withdrawal: $2.47 \pm 0.48 \mu\text{V}$; approach: $1.83 \pm 0.43 \mu\text{V}$; $d = 0.64$, $p = .02$, 95% CI [0.13, 1.15]). However, this difference was not significant in the late phase (withdrawal: $1.13 \pm 0.43 \mu\text{V}$; approach: $1.24 \pm 0.42 \mu\text{V}$; $d = -.029$, $p = -.71$, 95% CI [-0.68, 0.47]).

3.4 | ERPs mediate the effect of motivational intensity on emotion regulation choice

To further explore how the processing of stimuli impacts individuals' emotion regulation, we examined the role of P2 and LPPs in the effect of motivational intensity on strategy selection by mediation analyses, respectively.

Following the principles of mediation analysis (Baron & Kenny, 1986; Wen & Ye, 2014), we examined the mediation effect step by step, with ERP components serving as mediators respectively. As mentioned before, we can calculate the standardized regression coefficients from each ERP indicator to the reappraisal choice (POR) with intensity and direction as control variables for each participant, and all coefficients were then entered into a one-sample group mean test (compared to zero), treating subjects as a random effect.

For P2, the average of the regression coefficients was significant at the Fz site and presented negativity ($B_{P2_Fz} = -0.20 \pm 0.56$, $t(57) = -2.80$, $p < .01$, 95% CI [-0.35, -0.06]), whereas it was not significant at the Cz and Pz sites ($ps > .20$, shown in Table 3). For LPPs, the average coefficient of the early LPP, rather than that of the middle or late LPPs, was negative and significantly different from zero ($B_{LPP_Early} = -0.11 \pm 0.40$, $t(57) = -2.20$, $p = .03$, 95% CI [-0.22, -0.01]). All these results indicated that the enhanced frontal P2 and early LPP were associated with the reduced proportion of reappraisal.

Given the significant influence of motivational intensity on the information processing (frontal P2 and early-LPP) and emotion regulation choice, we tested whether the relationship between motivational intensity and ER choice would alter with frontal P2 and early-LPP as co-variables, respectively. The statistical results showed that the effect of motivational intensity disappeared after controlling the contribution of neurophysiological activities, $B_{\text{control}(LPP_Early)} = -0.14 \pm 0.89$, $t(57) = -1.17$, $p = .25$, 95% CI [-0.37, 0.10]; $B_{\text{control}(P2_Fz)} = 0.01 \pm 1.26$, $t(57) = 0.07$, $p = .95$, 95% CI [-0.32, 0.34] (see Figure 5). According to the conditions of the mediation effect (Baron & Kenny, 1986; Wen & Ye, 2014), mediating variables should significantly

TABLE 3 The mean regression coefficients for the ERP indicators on the choice of reappraisal.

| ERP components | B (SD) | <i>t</i> | <i>p</i> | 95% CI |
|----------------|--------------|----------|----------|----------------|
| P2-Fz | -0.20 (0.56) | -2.78 | <.01 | [-0.35, -0.06] |
| P2-Cz | 0.19 (1.25) | 1.15 | .26 | [-0.14, 0.52] |
| P2-Pz | 0.20 (1.15) | 1.30 | .20 | [-0.11, 0.50] |
| LPP-Early | -0.11 (0.40) | -2.20 | .03 | [-0.22, -0.01] |
| LPP-Middle | -0.09 (0.64) | -1.08 | .28 | [-0.26, 0.08] |
| LPP-Late | -0.04 (0.34) | -0.88 | .38 | [-0.13, 0.05] |

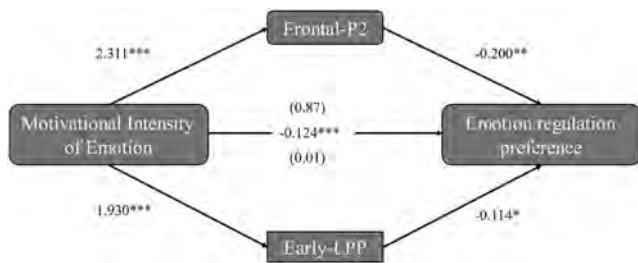


FIGURE 5 The relationship between motivational intensity and emotion regulation choice was mediated by frontal P2 and early LPP.

predict the dependent variable after controlling for the contribution of the independent variable. Our results indicate that P2 and early-LPP mediated the influence of motivational intensity on emotion regulation preference.

4 | DISCUSSION

Motivation, as a core attribute of emotion, is proven to shape individuals' emotional regulatory choices, yet its neural mechanisms remain unclear. This study examines how the different aspects of motivation influence rapid emotion processing, and in turn, determine the choice of emotion regulatory strategies by EEG approach. Replicating previous findings, increased motivational intensity was associated with a greater likelihood of employing distraction over reappraisal. This was neurophysiologically indexed by a frontal P2 and an early LPP at the posterior-occipital region that serves as brain mediators in the relationship between motivational intensity and ER choice. These findings suggest that the selection of emotion regulatory strategies may occur in the early stage of emotional information processing, where individuals' responses are mainly influenced by the inherent properties of emotional stimuli rather than the advanced semantic appraisal.

In this study, our key findings indicate that emotion with high-intensity motivation led to greater frontal P2 and early LPP, encouraging a preference for distraction over reappraisal in the subsequent ER choice; in contrast, smaller P2 and early LPP elicited by low-intensity motivated stimuli are associated with a greater tendency to use reappraisal. One possible explanation is the theory that individuals have a limited capacity for attention and mental effort (Desimone & Duncan, 1995; Kahneman, 1973). Such a limitation imposes permanent processing constraints resulting in a constant competition between emotion generation and emotion regulation processes (Sheppes, 2014). The P2 is associated with the rapid detection of emotional stimuli (Carretié et al., 2013; Kanske, Plitschka, & Kotz, 2011) and reflects

the allocation of attentional resources at the initial stage of emotional processing (Carretié et al., 2001; Wang et al., 2019). The early LPP is considered an indicator of motivated attention (Ferrari et al., 2008; Hajcak & Dennis, 2009). Thus, larger frontal P2 and early LPP triggered by high-intensity motivational stimuli suggest that they can recruit more visual-processing resources and motivated attention, diminishing resources available for the subsequent emotion regulation processes. Considering that implementing reappraisal requires more cognitive resources and effort than distraction (Shafir et al., 2015), individuals tend to opt for distraction with their attention heavily occupied by intense emotions.

Moreover, previous studies have linked larger P2 and early-LPP to the enhanced loss minimization and gain maximization (Martín et al., 2013). In the emotion regulation choice task, individuals were required to select between two competing strategies, investing efforts into the implementation of the selected strategy whose effectiveness is yet uncertain. Effort investment typically evokes aversive responses akin to losses in decision-making tasks (Kool & Botvinick, 2018; Wu et al., 2023); while the outcome of strategy execution in emotion regulation could be regarded as the gains (Hu & Gasper, 2023). The heightened frontal P2 and early LPP elicited by high-intensity motivated stimuli suggest amplified sensitivity to loss and gain, leading individuals to choose the option that promises maximum gain with minimal effort. Consistent with this requirement, individuals prefer distraction over reappraisal in high-intensity motivated emotional contexts, as distraction requires less effort and effectively regulates intense emotions (Shafir et al., 2015; Sheppes & Meiran, 2008).

Notably, although the largest P2 is recorded in the posterior area (Pz site), only the frontal P2 amplitudes elicited by emotional stimuli are associated with the subsequent emotion regulation choices. In previous studies, amplified P2 responses were mostly captured in attended task-relevant stimuli and emotional stimuli (Kanske, Heissler, et al., 2011). Specifically, studies involving general attention-related tasks like the character searching task (Freunberger et al., 2007; Hickey et al., 2006), and visuospatial task (Babiloni et al., 2006; Potts, 2004), demonstrated the modulation of P2 in both anterior and posterior brain areas. By contrast, the impact of emotion on P2 predominantly manifests in anterior brain regions (e.g., Junhong et al., 2013; Yuan et al., 2007). For instance, negative scenes (Carretié et al., 2006; Yuan et al., 2007) and faces (Carretié et al., 2013; Schindler & Bublitzky, 2020) elicited enhanced frontal P2 compared to positive images. A review of 55 experiments on automatic attention to emotional stimuli by Carretié (2014),

indicates that while both the anterior and posterior regions contribute to P2 generation, the former exhibits greater sensitivity to the emotional attributes of stimuli. In line with these findings, our study found that frontal P2 rather than posterior P2 elicited by emotional images, correlates with the subsequent choice of emotion regulatory strategies, highlighting the distinctive involvement of the frontal cortex in the initial stages of emotion processing.

Furthermore, we found that only the early LPP demonstrated a significant association with individuals' choice of emotion regulatory strategies between distraction and reappraisal; interestingly, neither the middle nor late LPP exhibited such a relationship. This replicates previous research linking increased LPP to a preference for distraction over reappraisal (Shafir et al., 2016), and further emphasizes the temporal dynamics of emotional modulation in the LPP (Hajcak et al., 2009; Paul et al., 2016). The early LPP is often seen as the manifestation of motivated attention to emotional stimuli (Hajcak et al., 2007), sharing similarities in timing and topography to the target-elicited P300 commonly observed in oddball tasks (e.g., Smith et al., 1990; Yuan et al., 2012). According to the context updating model (Donchin & Coles, 1988; Fields, 2023), P3 is associated with utilizing stimulus information to enhance later processing and response. Specifically, it involves constructing adaptive models of the context that help individuals take strategic actions to pursue their goals (Donchin & Coles, 1988). Aligning with this model, our findings suggest that increased early LPP elicited by high-intensity motivated stimuli correlates with a greater likelihood of using distraction, which may be more adaptive than reappraisal to regulate intense emotions (Aldao & Nolen-Hoeksema, 2012; Shafir et al., 2015). On the other hand, the middle LPP (500–1000 ms) is considered to involve the semantic processing of emotional stimuli (Olofsson et al., 2008). Also, the late LPP (starting at 1000 ms) might reflect automatic emotional regulation processes (Harrison & Chassy, 2017; Zhang et al., 2023). As these later LPPs may be influenced by factors beyond the emotional attributes of stimuli, such as individual beliefs in emotional controllability (Huang et al., 2023), they are potentially less indicative of an individual's subsequent choice of emotion regulation strategies.

Inconsistent with the negativity bias of emotional processing (Carretié et al., 2001), this study found that positive approach-motivated emotional stimuli elicited enhanced P2 amplitudes compared to negative withdrawal-motivated emotional stimuli. This may be due to our experiment manipulation. In our experiment, participants were instructed to regulate their emotions to a state of calmness after initial exposure to emotional images,

regardless of whether those emotions were positive approach-motivated or negative, withdrawal-motivated. Therefore, in approach-motivated conditions, participants had to down-regulate their positive approach-motivated emotions, against their intrinsic need to enjoy pleasure; in contrast, the down-regulation of negative withdrawal-motivated emotion matches internal needs. Previous research indicates that stimulus processing in the brain around 200 ms post-stimulus represents early automatic, involuntary processing (Cul et al., 2007). In this regard, the observed attention bias for emotional stimuli as well as differential attention allocation for stimuli varying in motivation, probably occurred involuntarily at this stage. As a result, potential involuntary reconciliation between the innate need of experiencing positively approach-motivated emotion and the overt requirement of emotion downregulation may have engaged more attention resources, leading to a larger P2 than in withdrawal-motivated conditions. With the involvement of consciousness, attention was primarily guided by top-down mechanisms, and stimuli associated with high-withdrawal motivation triggered more significant parietal-occipital LPPs than high-approach motivated stimuli, contrary to the pattern observed in the P2 stage.

Finally, the behavioral results indicated that increased motivation was associated with more preference for distraction over reappraisal in negative withdrawal-motivated conditions, replicating our previous findings (Yang et al., 2021), while this effect disappeared in positive approach-motivated conditions. Affective states high in withdrawal motivation, such as disgust and fear, are closely associated with individual survival (Gable & Harmon-Jones, 2010a; Larson & Steuer, 2009). Employing distraction in such cases can effectively regulate intense emotional responses without altering the salience of the stimuli, enabling individuals to remain vigilant in similar conditions and thus enhance survival (Hermann et al., 2017; Paul et al., 2016). In contrast, affective states characterized by low withdrawal motivation, are often induced by social contexts (e.g., sadness and frustration; Gable & Harmon-Jones, 2010a), and thus benefit cognitive reappraisal. Reappraisal in such contexts allows individuals to redirect aversive feelings positively, promoting resilience and social adaptation (Elliot, 2006; Mauersberger et al., 2018). Besides, given that the approach-motivated emotional situations are mostly positive and enjoyable (Harmon-Jones et al., 2011), participants' inclination to down-reappraise them is kept at a medium level, whether the stimulus is high or low in motivational intensity.

In summary, this study contributes to the current understanding of how the motivational intensity of emotional events influences emotion regulation choice between

distraction and reappraisal by elucidating the neurophysiological activities of the brain. The frontal P2 and the early LPP elicited by high-intensity motivated stimuli are both associated with more frequent choices of distraction over reappraisal, possibly due to these two components being more sensitive to motivational attributes and involving automatic attentional processing, respectively. Moreover, these two components act as mediators in the relationships between motivational intensity and emotion regulation choices, stressing the function of early selective attention and motivated attention in emotional processing and decision-making. These findings should be considered the effects of motivational intensity, as the arousal was controlled across different intensity conditions.

Several limitations need to be acknowledged. First, our study employed a forced-choice paradigm, where participants had to select between distraction and reappraisal. Although this task has proven to be valid in detecting individuals' strategy choices in laboratory contexts, it may not fully reflect individuals' typical emotional responses in daily life, where multiple strategies are available and the different strategic choices are interdependent. Second, our focus lies on the selection of regulatory strategy in emotional contexts with varying motivations, leaving the subsequent implementation of the chosen strategy and the monitoring stage unexplored. Recent conceptual models propose that emotion regulation is composed of several interactive stages, including identification, selection, implementation, and monitoring (Gross, 2015; Sheppes, 2020). Specifically, apart from strategy selection, the regulatory monitoring involves whether to sustain, adjust, or cease the actively implemented strategy. It also plays a crucial role in maximizing adaptive outcomes. For instance, previous studies have indicated that individuals are more inclined to switch strategies after employing reappraisal to regulate intense emotions (Dorman Ilan et al., 2019; Toh & Yang, 2024). Therefore, future research could delve into the monitoring and adjustment during emotion regulation, shedding light on the flexibility and adaptability of these regulatory mechanisms.

AUTHOR CONTRIBUTIONS

Xinyu Yan: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; software; validation; visualization; writing – original draft; writing – review and editing. **Wei Gao:** Conceptualization; formal analysis; writing – review and editing. **Jiemin Yang:** Funding acquisition; supervision; writing – review and editing. **Salvatore Campanella:** Supervision; writing – review and editing. **Jiajin Yuan:** Conceptualization; funding acquisition; methodology; project administration; resources; supervision; visualization; writing – review and editing.

FUNDING INFORMATION

This research was supported by the National Natural Science Foundation of China (31971018 and 31871103), Science Fund for Distinguished Young Scholars of Sichuan Province (2023NSFSC1938), and the Grant of Chinese Scholarship Council (202407650041).

CONFLICT OF INTEREST STATEMENT

The authors declared that the research was conducted in the absence of any commercial or financial relationship that could be constructed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available at OFS (<https://osf.io/y6qnh/>).

ORCID

Jiajin Yuan  <https://orcid.org/0000-0002-5630-2230>

REFERENCES

- Aldao, A., & Nolen-Hoeksema, S. (2012). The influence of context on the implementation of adaptive emotion regulation strategies. *Behaviour Research and Therapy*, 50(7–8), 493–501.
- 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>
- Babiloni, C., Vecchio, F., Miriello, M., Romani, G. L., & Rossini, P. M. (2006). Visuo-spatial consciousness and parieto-occipital areas: A high-resolution EEG study. *Cerebral Cortex*, 16(1), 37–46. <https://doi.org/10.1093/cercor/bhi082>
- Barnett, S. B., & Cerf, M. (2017). A ticket for your thoughts: Method for predicting content recall and sales using neural similarity of moviegoers. *Journal of Consumer Research*, 44(1), 160–181. <https://doi.org/10.1093/jcr/ucw083>
- Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, 51(6), 1173–1182. <https://doi.org/10.1037/0022-3514.51.6.1173>
- Bublitzky, F., & Schupp, H. T. (2012). Pictures cueing threat: Brain dynamics in viewing explicitly instructed danger cues. *Social Cognitive and Affective Neuroscience*, 7(6), 611–622. <https://doi.org/10.1093/scan/nsr032>
- Carretié, L. (2014). Exogenous (automatic) attention to emotional stimuli: A review. *Cognitive, Affective, & Behavioral Neuroscience*, 14(4), 1228–1258. <https://doi.org/10.3758/s13415-014-0270-2>
- Carretié, L., Hinojosa, J. A., Albert, J., & Mercado, F. (2006). Neural response to sustained affective visual stimulation using an indirect task. *Experimental Brain Research*, 174(4), 630–637. <https://doi.org/10.1007/s00221-006-0510-y>
- Carretié, L., Kessel, D., Carboni, A., López-Martín, S., Albert, J., Tapia, M., Mercado, F., Capilla, A., & Hinojosa, J. A. (2013). Exogenous attention to facial vs non-facial emotional visual stimuli. *Social Cognitive and Affective Neuroscience*, 8(7), 764–773. <https://doi.org/10.1093/scan/nss068>

- Carretié, L., Mercado, F., Tapia, M., & Hinojosa, J. A. (2001). Emotion, attention, and the 'negativity bias', studied through event-related potentials. *International Journal of Psychophysiology*, *41*(1), 75–85. [https://doi.org/10.1016/S0167-8760\(00\)00195-1](https://doi.org/10.1016/S0167-8760(00)00195-1)
- Castellar, E. N., Kühn, S., Fias, W., & Notebaert, W. (2010). Outcome expectancy and not accuracy determines posterror slowing: ERP support. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(2), 270–278. <https://doi.org/10.3758/CABN.10.2.270>
- Cul, A. D., Baillet, S., & Dehaene, S. (2007). Brain dynamics underlying the nonlinear threshold for access to consciousness. *PLoS Biology*, *5*(10), e260. <https://doi.org/10.1371/journal.pbio.0050260>
- Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, *52*(2), 95–111. [https://doi.org/10.1016/S0301-0511\(99\)00044-7](https://doi.org/10.1016/S0301-0511(99)00044-7)
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193–222. <https://doi.org/10.1146/annurev.ne.18.030195.001205>
- Dieterich, R., Endrass, T., & Kathmann, N. (2016). Uncertainty is associated with increased selective attention and sustained stimulus processing. *Cognitive, Affective, & Behavioral Neuroscience*, *16*(3), 447–456. <https://doi.org/10.3758/s13415-016-0405-8>
- Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, *11*(3), 357–374. <https://doi.org/10.1017/S0140525X00058027>
- Dorman, I., Shafir, R., Birk, J. L., Bonanno, G. A., & Sheppes, G. (2019). Monitoring in emotion regulation: Behavioral decisions and neural consequences. *Social Cognitive and Affective Neuroscience*, *14*(12), 1273–1283. <https://doi.org/10.1093/scan/nsaa001>
- Elliot, A. J. (2006). The hierarchical model of approach-avoidance motivation. *Motivation and Emotion*, *30*(2), 111–116.
- Ferrari, V., Codispoti, M., Cardinale, R., & Bradley, M. M. (2008). Directed and motivated attention during processing of natural scenes. *Journal of Cognitive Neuroscience*, *20*(10), 1753–1761. <https://doi.org/10.1162/jocn.2008.20121>
- Fields, E. C. (2023). The P300, the LPP, context updating, and memory: What is the functional significance of the emotion-related late positive potential? *International Journal of Psychophysiology*, *192*, 43–52. <https://doi.org/10.1016/j.ijpsycho.2023.08.005>
- Flores, A., Münte, T. F., & Doñamayor, N. (2015). Event-related EEG responses to anticipation and delivery of monetary and social reward. *Biological Psychology*, *109*, 10–19. <https://doi.org/10.1016/j.biopsycho.2015.04.005>
- Foti, D., & Hajcak, G. (2008). Deconstructing reappraisal: Descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience*, *20*(6), 977–988. <https://doi.org/10.1162/jocn.2008.20066>
- Freunberger, R., Klimesch, W., Doppelmayr, M., & Höller, Y. (2007). Visual P2 component is related to theta phase-locking. *Neuroscience Letters*, *426*(3), 181–186. <https://doi.org/10.1016/j.neulet.2007.08.062>
- Gable, P., & Harmon-Jones, E. (2010a). The blues broaden, but the nasty narrows: Attentional consequences of negative affects low and high in motivational intensity. *Psychological Science*, *21*(2), 211–215. <https://doi.org/10.1177/0956797609359622>
- Gable, P., & Harmon-Jones, E. (2010b). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorisation. *Cognition and Emotion*, *24*(2), 322–337. <https://doi.org/10.1080/02699930903378305>
- Gable, P. A., & Adams, D. L. (2013). Non-affective motivation modulates the sustained LPP (1,000–2,000ms). *Psychophysiology*, *50*(12), 1251–1254. <https://doi.org/10.1111/psyp.12135>
- Gross, J. J. (2015). Emotion regulation: Current status and future prospects. *Psychological Inquiry*, *26*(1), 1–26. <https://doi.org/10.1080/1047840X.2014.940781>
- Hajcak, G., & Dennis, T. A. (2009). Brain potentials during affective picture processing in children. *Biological Psychology*, *80*(3), 333–338. <https://doi.org/10.1016/j.biopsycho.2008.11.006>
- Hajcak, G., Dunning, J. P., & Foti, D. (2007). Neural response to emotional pictures is unaffected by concurrent task difficulty: An event-related potential study. *Behavioral Neuroscience*, *121*(6), 1156–1162. <https://doi.org/10.1037/0735-7044.121.6.1156>
- Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology*, *120*(3), 505–510. <https://doi.org/10.1016/j.clinph.2008.11.028>
- Hajcak, G., & Foti, D. (2020). Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. *Psychophysiology*, *57*(7), e13570. <https://doi.org/10.1111/psyp.13570>
- Hakim, A., Golan, I., Yefet, S., & Levy, D. J. (2023). DeePay: Deep learning decodes EEG to predict consumer's willingness to pay for neuromarketing. *Frontiers in Human Neuroscience*, *17*, 1153413. <https://doi.org/10.3389/fnhum.2023.1153413>
- Hammerschmidt, W., Sennhenn-Reulen, H., & Schacht, A. (2017). Associated motivational salience impacts early sensory processing of human faces. *NeuroImage*, *156*, 466–474. <https://doi.org/10.1016/j.neuroimage.2017.04.032>
- Harmon-Jones, E. (2019). On motivational influences, moving beyond valence, and integrating dimensional and discrete views of emotion. *Cognition and Emotion*, *33*(1), 101–108. <https://doi.org/10.1080/02699931.2018.1514293>
- Harmon-Jones, E., Harmon-Jones, C., Amodio, D. M., & Gable, P. A. (2011). Attitudes toward emotions. *Journal of Personality and Social Psychology*, *101*(6), 1332–1350. <https://doi.org/10.1037/a0024951>
- Harrison, N. R., & Chassy, P. (2017). Habitual use of cognitive reappraisal is associated with decreased amplitude of the late positive potential (LPP) elicited by threatening pictures. *Journal of Psychophysiology*, *33*(1), 22–31. <https://econtent.hogrefe.com/doi/10.1027/0269-8803/a000202>
- Hendricks, M. A., & Buchanan, T. W. (2016). Individual differences in cognitive control processes and their relationship to emotion regulation. *Cognition and Emotion*, *30*(5), 912–924. <https://doi.org/10.1080/02699931.2015.1032893>
- Hermann, A., Kress, L., & Stark, R. (2017). Neural correlates of immediate and prolonged effects of cognitive reappraisal and distraction on emotional experience. *Brain Imaging and Behavior*, *11*(5), 1227–1237. <https://doi.org/10.1007/s11682-016-9603-9>
- Hickey, C., McDonald, J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience*, *18*, 604–613. <https://doi.org/10.1162/jocn.2006.18.4.604>
- Hill, L. D., Starratt, V. G., Fernandez, M., & Tartar, J. L. (2019). Positive affective priming decreases the middle late positive potential response to negative images. *Brain and Behavior: A*

- Cognitive Neuroscience Perspective, 9(1), e01198. <https://doi.org/10.1002/brb3.1198>
- Hu, D., & Gasper, K. (2023). Useful and affordable? How costs and benefits uniquely shape motivated emotion regulation. *Motivation Science*, 9(4), 315–326. <https://doi.org/10.1037/mot0000309>
- Huang, Y., Zhang, Q., Shang, C., & Cui, L. (2023). How do fundamental emotion beliefs affect the rapid emotional processing? An ERP study. *International Journal of Psychophysiology*, 191, 19–28. <https://doi.org/10.1016/j.ijpsycho.2023.06.010>
- Junhong, H., Renlai, Z., & Senqi, H. (2013). Effects on automatic attention due to exposure to pictures of emotional faces while performing Chinese word judgment tasks. *PLoS One*, 8(10), e75386. <https://doi.org/10.1371/journal.pone.0075386>
- Kahneman, D. (1973). *Attention and effort* (Vol. 1063, pp. 218–226). Prentice-Hall.
- Kanske, P., Heissler, J., Schönfelder, S., Bongers, A., & Wessa, M. (2011). How to regulate emotion? Neural networks for re-appraisal and distraction. *Cerebral Cortex*, 21(6), 1379–1388. <https://doi.org/10.1093/cercor/bhq216>
- Kanske, P., Plitschka, J., & Kotz, S. A. (2011). Attentional orienting towards emotion: P2 and N400 ERP effects. *Neuropsychologia*, 49(11), 3121–3129. <https://doi.org/10.1016/j.neuropsychologia.2011.07.022>
- Kappenman, E. S., & Luck, S. J. (Eds.). (2011). *The Oxford handbook of event-related potential components* (1st ed.). Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780195374148.001.0001>
- Koch, S., Holland, R. W., & van Knippenberg, A. (2008). Regulating cognitive control through approach-avoidance motor actions. *Cognition*, 109(1), 133–142. <https://doi.org/10.1016/j.cognition.2008.07.014>
- Kool, W., & Botvinick, M. (2018). Mental labour. *Nature human behaviour*, 2(12), article 12. <https://doi.org/10.1038/s41562-018-0401-9>
- Kuo, J. R., Fitzpatrick, S., Krantz, L. H., & Zeifman, R. J. (2018). How do you choose and how well does it work?: The selection and effectiveness of emotion regulation strategies and their relationship with borderline personality disorder feature severity. *Cognition and Emotion*, 32(3), 632–640. <https://doi.org/10.1080/02699931.2017.1330254>
- Kurdi, B., Lozano, S., & Banaji, M. R. (2017). Introducing the open affective standardized image set (OASIS). *Behavior Research Methods*, 49, 457–470. <https://doi.org/10.3758/s13428-016-0715-3>
- Lang, P. J., Bradley, B. N., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual* (Technical Report No. A-8). University of Florida.
- Larson, C., & Steuer, E. (2009). Motivational relevance as a potential modulator of memory for affective stimuli: Can we compare snakes and cakes? *Emotion Review*, 1, 116–117. <https://doi.org/10.1177/1754073908100434>
- Liu, L., Zhang, G., Zhou, R., & Wang, Z. (2014). Motivational intensity modulates attentional scope: Evidence from behavioral and ERP studies. *Experimental Brain Research*, 232(10), 3291–3300. <https://doi.org/10.1007/s00221-014-4014-x>
- Liu, Y., Huang, H., McGinnis-Deweese, M., Keil, A., & Ding, M. (2012). Neural substrate of the late positive potential in emotional processing. *The Journal of Neuroscience*, 32(42), 14563–14572. <https://doi.org/10.1523/JNEUROSCI.3109-12.2012>
- Livermore, J. J. A., Klaassen, F. H., Bramson, B., Hulsman, A. M., Meijer, S. W., Held, L., Klumpers, F., de Voogd, L. D., & Roelofs, K. (2021). Approach-avoidance decisions under threat: The role of autonomic psychophysiological states. *Frontiers in Neuroscience*, 15: 621517. <https://doi.org/10.3389/fnins.2021.621517>
- Luck, S. J. (2014). *An introduction to the event-related potential technique (second edition)*. The MIT Press.
- Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, 54(1), 146–157. <https://doi.org/10.1111/psyp.12639>
- Luck, S. J., Stewart, A. X., Simmons, A. M., & Rhemtulla, M. (2021). Standardized measurement error: A universal metric of data quality for averaged event-related potentials. *Psychophysiology*, 58(6), e13793. <https://doi.org/10.1111/psyp.13793>
- Martin, R. S., Appelbaum, L. G., Pearson, J. M., Huettel, S. A., & Woldorff, M. G. (2013). Rapid brain responses independently predict gain maximization and loss minimization during economic decision making. *Journal of Neuroscience*, 33(16), 7011–7019. <https://doi.org/10.1523/JNEUROSCI.4242-12.2013>
- Matsuda, I., & Nittono, H. (2015). Motivational significance and cognitive effort elicit different late positive potentials. *Clinical Neurophysiology*, 126(2), 304–313. <https://doi.org/10.1016/j.clinph.2014.05.030>
- Mauersberger, H., Hoppe, A., Brockmann, G., & Hess, U. (2018). Only reappraisers profit from reappraisal instructions: Effects of instructed and habitual reappraisal on stress responses during interpersonal conflicts. *Psychophysiology*, 55(9), e13086. <https://doi.org/10.1111/psyp.13086>
- Milyavsky, M., Fernandez, J. R., Kruglanski, A. W., Suri, G., Webber, D., Goldenberg, A., & Gross, J. J. (2019). *To reappraise or not to reappraise?* Emotion Regulation Choice and Cognitive Energetics. 19(6), 964. <http://dx.doi.org/10.1037/emo0000498>
- Moodie, C. A., Suri, G., Goerlitz, D. S., Mateen, M. A., Sheppes, G., McRae, K., ... Gross, J. J. (2020). The neural bases of cognitive emotion regulation: The roles of strategy and intensity. *Cognitive, Affective, & Behavioral Neuroscience*, 20, 387–407.
- Moyal, N., Stelmach-Lask, L., Anholt, G. E., & Henik, A. (2023). Choosing an emotion regulation strategy—the importance of emotional category. *Journal of Affective Disorders Reports*, 12, 100498. <https://doi.org/10.1016/j.jadr.2023.100498>
- Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology*, 77(3), 247–265. <https://doi.org/10.1016/j.biopsycho.2007.11.006>
- Paul, S., Kathmann, N., & Riesel, A. (2016). The costs of distraction: The effect of distraction during repeated picture processing on the LPP. *Biological Psychology*, 117, 225–234. <https://doi.org/10.1016/j.biopsycho.2016.04.002>
- Potts, G. F. (2004). An ERP index of task relevance evaluation of visual stimuli. *Brain and Cognition*, 56(1), 5–13. <https://doi.org/10.1016/j.bandc.2004.03.006>
- Schindler, S., & Bublatzky, F. (2020). Attention and emotion: An integrative review of emotional face processing as a function of attention. *Cortex*, 130, 362–386. <https://doi.org/10.1016/j.cortex.2020.06.010>
- Schindler, S., & Straube, T. (2020). Selective visual attention to emotional pictures: Interactions of task-relevance and emotion are restricted to the late positive potential. *Psychophysiology*, 57(9), e13585. <https://doi.org/10.1111/psyp.13585>

- Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology*, 37(2), 257–261. <https://doi.org/10.1111/1469-8986.3720257>
- Schupp, H. T., & Kirmse, U. M. (2021). Case-by-case: Emotional stimulus significance and the modulation of the EPN and LPP. *Psychophysiology*, 58(4), e13766. <https://doi.org/10.1111/psyp.13766>
- Shafir, R., Schwartz, N., Blechert, J., & Sheppes, G. (2015). Emotional intensity influences pre-implementation and implementation of distraction and reappraisal. *Social Cognitive and Affective Neuroscience*, 10(10), 1329–1337. <https://doi.org/10.1093/scan/nsv022>
- Shafir, R., Thiruchselvam, R., Suri, G., Gross, J. J., & Sheppes, G. (2016). Neural processing of emotional-intensity predicts emotion regulation choice. *Social Cognitive and Affective Neuroscience*, 11(12), 1863–1871. <https://doi.org/10.1093/scan/nsw114>
- Sheppes, G. (2014). Emotion regulation choice: Theory and findings. *Handbook of Emotion Regulation*, 2, 126–139.
- Sheppes, G. (2020). Transcending the “good & bad” and “here & now” in emotion regulation: Costs and benefits of strategies across regulatory stages. In *Advances in experimental social psychology* (Vol. 61, pp. 185–236). Elsevier. <https://doi.org/10.1016/bs.aesp.2019.09.003>
- Sheppes, G., & Meiran, N. (2007). Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. *Personality and Social Psychology Bulletin*, 33(11), 1518–1532. <https://doi.org/10.1177/0146167207305537>
- Sheppes, G., & Meiran, N. (2008). Divergent cognitive costs for online forms of reappraisal and distraction. *Emotion*, 8(6), 870–874. <https://doi.org/10.1037/a0013711>
- Sheppes, G., Scheibe, S., Suri, G., & Gross, J. J. (2011). Emotion-regulation choice. *Psychological Science*, 22(11), 1391–1396. <https://doi.org/10.1177/0956797611418350>
- Sheppes, G., Scheibe, S., Suri, G., Radu, P., Blechert, J., & Gross, J. J. (2014). Emotion regulation choice: A conceptual framework and supporting evidence. *Journal of Experimental Psychology: General*, 143(1), 163–181. <https://doi.org/10.1037/a0030831>
- Smith, M. E., Halgren, E., Sokolik, M., Baudena, P., Musolino, A., Liegeois-Chauvel, C., & Chauvel, P. (1990). The intracranial topography of the P3 event-related potential elicited during auditory oddball. *Electroencephalography and Clinical Neurophysiology*, 76(3), 235–248. [https://doi.org/10.1016/0013-4694\(90\)90018-F](https://doi.org/10.1016/0013-4694(90)90018-F)
- Thiruchselvam, R., Blechert, J., Sheppes, G., Rydstrom, A., & Gross, J. J. (2011). The temporal dynamics of emotion regulation: An EEG study of distraction and reappraisal. *Biological Psychology*, 87(1), 84–92. <https://doi.org/10.1016/j.biopsycho.2011.02.009>
- Thom, N., Knight, J., Dishman, R., Sabatinelli, D., Johnson, D. C., & Clementz, B. (2014). Emotional scenes elicit more pronounced self-reported emotional experience and greater EPN and LPP modulation when compared to emotional faces. *Cognitive, Affective, & Behavioral Neuroscience*, 14(2), 849–860. <https://doi.org/10.3758/s13415-013-0225-z>
- Toh, W. X., & Yang, H. (2024). To switch or not to switch? Individual differences in executive function and emotion regulation flexibility. *Emotion*, 24(1), 52–66. <https://doi.org/10.1037/emo0001250>
- Wang, X., Shangguan, C., & Lu, J. (2019). Time course of emotion effects during emotion-label and emotion-laden word processing. *Neuroscience Letters*, 699, 1–7. <https://doi.org/10.1016/j.neulet.2019.01.028>
- Weinberg, A., & Hajcak, G. (2010). Beyond good and evil: The time-course of neural activity elicited by specific picture content. *Emotion*, 10(6), 767–782. <https://doi.org/10.1037/a0020242>
- Weinberg, A., & Hajcak, G. (2011). The late positive potential predicts subsequent interference with target processing. *Journal of Cognitive Neuroscience*, 23(10), 2994–3007. <https://doi.org/10.1162/jocn.2011.21630>
- Wen, Z., & Ye, B. (2014). Analyses of mediating effects: The development of methods and models. *Advances in Psychological Science*, 22(5), 731. <https://doi.org/10.3724/SP.J.1042.2014.00731>
- Wu, R., Ferguson, A. M., & Inzlicht, M. (2023). Do humans prefer cognitive effort over doing nothing? *Journal of Experimental Psychology: General*, 152(4), 1069–1079. <https://doi.org/10.1037/xge0001320>
- Yang, J., Yan, X., Chen, S., Liu, W., Zhang, X., & Yuan, J. (2021). Increased motivational intensity leads to preference for distraction over reappraisal during emotion regulation: Mediated by attentional breadth. *Emotion*, 22, 1595–1603.
- Yuan, J., Xu, S., Li, C., Yang, J., Li, H., Yuan, Y., & Huang, Y. (2012). The enhanced processing of visual novel events in females: ERP correlates from two modified three-stimulus oddball tasks. *Brain Research*, 1437, 77–88. <https://doi.org/10.1016/j.brainres.2011.12.017>
- Yuan, J., Zhang, Q., Chen, A., Li, H., Wang, Q., Zhuang, Z., & Jia, S. (2007). Are we sensitive to valence differences in emotionally negative stimuli? Electrophysiological evidence from an ERP study. *Neuropsychologia*, 45(12), 2764–2771. <https://doi.org/10.1016/j.neuropsychologia.2007.04.018>
- Zhang, Y., Sijin, L., 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, 1278–1288. <https://doi.org/10.1007/s12264-023-01036-7>
- Zhang, Z., & Yuan, K.-H. (2018). Practical statistical power analysis using Webpower and R. <https://doi.org/10.35566/power>

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1.

How to cite this article: Yan, X., Gao, W., Yang, J., Campanella, S., & Yuan, J. (2024). Neurophysiological mechanisms underlying the influence of motivational intensity on emotion regulation choice. *Psychophysiology*, 00, e14722. <https://doi.org/10.1111/psyp.14722>