Emotion

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Effects of Working Memory Training on Different Goals of Cognitive Reappraisal

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Working memory training (WMT) has shown potential benefits in emotion regulation (ER), mainly in terms of improved ability to downregulate negative emotions in cognitive reappraisal. However, the goal of cognitive reappraisal can be not only to reduce negative emotion but also to increase negative emotion. It is not clear what effect WMT has on the upregulation of negative emotion. In the current study, we conducted a 20-day WMT with participants to explore the effects of training on the down- and upregulation of negative emotion and followed participants for 3 months after training to examine the persistent effects of training. Our results suggest that participants in the training group improved their ability to regulate negative emotions in both the down- and upregulation conditions. Notably, benefits from training were also observed in the look negative condition, suggesting that WMT may elicit general cognitive enhancement that is broadly transferable to any kind of negative situation to help individuals regulate the effects of negative emotions. In addition, our study also showed that the improvement in negative ER by training could last even over 3 months.

Keywords: working memory training, up- and downregulation of negative emotion, sustained improvement, ERPs

Supplemental materials: https://doi.org/10.1037/emo0001253.supp

Effective emotion regulation (ER) is crucial for maintaining healthy adaptation and intact social functioning (Berking & Wupperman, 2012; Eftekhari et al., 2009). It has been linked to positive outcomes, including overall well-being, job performance, and behavioral performance (Gross & John, 2003). Conversely, deficits in ER are believed to underlie emotional problems and disorders, which are associated with a broad range of psychiatric conditions (Berking & Wupperman, 2012).

Given the importance of ER, how to enhance it has gradually become a concern for researchers. Tamir et al. (2007) suggested that ER could be indirectly improved by training participants' cognitive abilities, such as working memory (WM), in a nonemotional environment. WM is a limited-capacity system for temporarily storing and processing information, and it is the basis of many higher cognitive activities (Baddeley, 2003). Recent studies have shown that the training for WM can lead to broad and profound transfer effects, such as improved reading comprehension, mathematical reasoning, and intelligence (Au et al., 2015; Melby-Lervåg & Hulme, 2013). When this transfer was extended to the emotional domain, researchers found that working memory training (WMT) had a significant improvement in emotional regulation (Beauchamp et al., 2016; Hoorelbeke et al., 2016; N. Cohen & Ochsner, 2018; Schweizer et al., 2013).

In studies of the effects of WMT on ER, researchers typically apply specific emotional situations before and after training, ask participants to complete an ER task, and analyze the changes in emotional regulation ability caused by training according to the changes in task indicators (electrocardiogram, electroencephalogram, or behavioral performance outcomes). For example, in Xiu et al.'s (2018) study, participants were asked to view a set of emotional images and regulate their emotions using cognitive reappraisal (i.e., reinterpreting the meaning of negative pictures) or distraction strategies (i.e., focusing attention on content unrelated to emotions) before and after the training. The impact of WMT on ER was examined by comparing the changes in participants' performance on ER tasks. For the choice of ER indicators, they used a classical event-related potential (ERP) component, the late positive potential (LPP), to assess changes in ER.

LPP is a positive-going deflection in the ERP waveform that begins approximately 400 ms after stimulus onset (MacNamara

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et al., 2022). It is used broadly to study the processing of emotional stimuli, and it has a greater effect on emotional stimuli than neutral stimuli (Hajcak & Foti, 2020). Based on the process of ER is a goal-oriented behavior and this regulation process will change the dynamic characteristics of emotions. Thus, LPP amplitude can change during ER. For example, the first work using ERP to study ER showed that a cognitive reappraisal strategy targeting downregulation of negative emotions was effective in reducing the LPP amplitude induced by negative pictures (Hajcak & Nieuwenhuis, 2006). Subsequent studies have verified that LPP amplitude tends to decrease during ER and can be used as an indicator of ER (Parvaz et al., 2015). Furthermore, in addition to using objective LPP indicators as indicators of changes in ER, subjective arousal and valence ratings for negative stimuli can also be used as behavioral indicators of ER. The results of Xiu et al. (2018) showed that after 20 days of WMT, the amplitude of LPP decreased in a cognitive reappraisal condition of downregulating negative emotions, indicating an improvement in individual ER. This result was also confirmed by the study of Pan et al. (2022).

However, cognitive reappraisal is not only used to psychologically downregulate (decrease) negative emotions, but in other cases, it can also be used to upregulate (increase) negative feelings, like an athlete developing aggression before a big game or someone imagining the worst when passing a traffic accident (Nolen-Hoeksema, 2000; Segerstrom et al., 2000). It has been shown that downregulation of negative emotion is more successful after WMT, but the effect of WMT on upregulation of negative emotion is unclear.

The Present Study

In the current study, we propose a hypothesis that after training, the effect of upregulating (increasing) negative emotion will be consistent with the effect of downregulating (decreasing) negative emotion, both in the direction of reducing the effect of negative emotion. That is to say, the amplitude of LPP will be significantly smaller after training compared to before training.

The neural and theoretical evidence supports our hypothesis to some extent. First, according to a study by Ochsner et al. (2004), upregulation of negative emotion was associated with an increase in amygdala activation, while downregulation of negative emotion was accompanied by a decrease in amygdala activation. The amygdala is thought to be a region closely related to threat detection and is part of the salience/defensive survival network. Another distinct network from the salience/defensive survival network is the central-executive control network (de Voogd, Hermans, & Phelps, 2018), activation in this network is seen during cognitively demanding tasks such as WM tasks (Daniel et al., 2016). The salience/defensive survival network and the central-executive control network are in competition with each other, with salience/defensive survival network activation weakening as central-executive network activity increases. For example, diminished activation of the amygdala is observed when completing WM tasks (de Voogd, Hermans, & Phelps, 2018; de Voogd, Kanen, et al., 2018). In our study, WMT was also a task that enhanced activation of the central-executive network, which would directly lead to reduced activation of the amygdala. Therefore, we hypothesized that after a period of WMT, this would result in better ER in both up- and downregulated negative emotion conditions, due to a generalized weakening of amygdala activation.

Second, upregulating negative emotion is a form of reappraisal that involves intensifying negative feelings. In this task, individuals deliberately place themselves in vulnerable situations by worrying, ruminating, or elaborating on the meaning of unpleasant events to make themselves more anxious and fearful. If more cognitive resources are available after WMT, individuals facing negative stressful situations may view the situation as a challenge, as per the biopsychosocial model (BPSM) of challenge and threat, and devote more resources to reducing the danger they face (Blascovich et al., 2000). Previous studies have demonstrated that WMT enhances cognitive resources (Schwarb et al., 2016). Thus, we predict that individuals will attempt to disarm the danger and reduce the impact of negative emotions by calling on the newly acquired cognitive resources, even under the instructions of upregulating negative emotions. That is to say, after training, we hypothesize that participants will show similar results in both upregulated and downregulated negative emotion conditions. To test the hypotheses, we set two cognitive reappraisal targets in the ER task: upregulated and downregulated negative emotions. We also included the look negative and look neutral conditions as baseline conditions, drawing from the study by Pan et al. (2022).

It is worth noting that our hypothesis is based on the assumption that WMT has far transfer effects on ER, which is supported by many studies (Beloe & Derakshan, 2020; Pan et al., 2022; Schweizer et al., 2013; Swainston & Derakshan, 2018). However, there are also some studies that hold the opposite view, suggesting that WMT does not improve ER (Li et al., 2016; Onraedt & Koster, 2014; Vanderhasselt et al., 2021). We attempt to argue that WMT can be effective in regulating emotions from the premise of transfer. Although ER is a far transfer, transfer is more likely to occur when performance on practice and transfer tasks rely on overlapping neural circuits (Bavelier et al., 2012). The ER process is accompanied by the activation of the dorsolateral prefrontal cortex (dlPFC), which is highly activated during WM tasks, indicating that WM and ER share the same neural substrate to a large extent, providing the neural overlap conditions for transfer. In addition, some studies have shown that the degree of variation encountered during training can influence the degree of transfer, with more variable training leading to greater transfer (Schmidt & Bjork, 1992). In recent studies that demonstrate the far transfer of WMT, long-term and challenging adaptive training tasks were completed (Swainston & Derakshan, 2018, 2021; Xiu et al., 2016, 2018). Therefore, based on the evidence of neural overlap and the adaptive nature of WMT, we believe that training can effectively transfer to ER.

In our study, in addition to focusing on the effects of training on different goals of cognitive reappraisal, we will also explore the persistence of this effect. Specifically, we will assess participants over a 3-month follow-up period to examine the long-term effects of WMT in up- and downregulating negative emotions. For the choice of training method, we trained participants using a modified version of the adaptive running WM task used by Xiu et al. (2018), which has been shown to be effective in improving ER. The current version increases the difficulty of the adaptive task and is more conducive to achieving far-transfer effects. Furthermore, we will collect task data reflecting WM ability in pre- and posttraining and follow-up tests, including response time and accuracy in 2-back and 3-back tasks, as an indicator of basic training effectiveness.

In general, in the current study, we attempted to answer two questions. First, what is the effect of WMT on the different targets of cognitive reappraisal (up- and downregulation of negative emotion)?

Second, could the effect of WMT on both upregulation and downregulation of negative emotion be sustainable?

Method

Participants

The sample size required for the experiment was calculated using the G*Power 3.1 software (Faul et al., 2007). Referring to published training studies (Wei et al., 2022; Xiu et al., 2018) and standards suggested by J. Cohen (1992), the parameters were set as follows: *F* test, repeated-measures analysis of variance (ANOVA), within-between factors, effect size = 0.25, $\alpha = .05$, $1 - \beta = 0.8$, number of groups = 2, number of measurements = 3. Then, we got the "total sample size" 28 using this procedure. As this number should be divided by "number of groups" according to G*Power, the final output of the calculation is 14(28/2 = 14). Given the long duration of the experiment, 25 participants were recruited for each group to avoid the impact of participant attrition on the experiment. All participants reported no history of affective disorders and were not taking any psychiatric medications. Participants had normal anxiety and depression scores (Beck Depression Inventory-II [BDI-II] scores <10 and Beck Anxiety Inventory [BAI] scores <45) on the BAI (Beck et al., 1988) and BDI-II (Beck et al., 1996) measures.

During the experiment, as some participants failed to complete the training task or the follow-up task on time, 42 participants remained at the end, 22 in the training group (M_{age}: 21.78 ± 1.93 years, males: 11) and 20 in the control group (M_{age}: 21.85 ± 2.08 years, males: 12). There were no significant differences in gender and age between participants in the training and control groups. All participants signed an informed consent form and were paid 78$ each at the end of the experiment. This study was approved by the Psychology Study Ethics Committee of Nanjing University (Approval number: NJUPSY 202010001).

Training Task

Participants trained for 20 days, about 30 min in each session, training was all done in the laboratory. We used the Running Memory task for the training group, this task is adaptive and has been shown in previous studies to be effective in improving WM (Xiu et al., 2016, 2018). The main tasks consisted of updating training for the phonological loop, updating training for a visual sketchpad, and updating training for a spatial sketchpad. It is worth noting that we have adapted the traditional running memory task. Specifically, the first 10 days of the training in the present study were all unidimensional update training. They were the digital memory, spatial location, and image memory tasks. While in the second 10 days, the task become more difficult, the training of the phonological loop was upgraded to memorize both letters and images; the visual sketchpad was upgraded to learn two images, and the updated training of the spatial template was upgraded from remembering the last three letters to remembering the last four letters. The improved version increases the type and difficulty of the adaptive tasks compared to the original version. This adaptation is in line with what Lövdén et al. (2010) define as "the basic prerequisite for successful cognitive training," that is, a mismatch or imbalance between environmental demands and actual brain supply. The training tasks are shown in Figure 1 (see Part 1 in the online supplemental materials for task details).

To evaluate the effects of a training intervention, it is crucial to compare the trained group to an active control group. This differentiates training effects not only from repetition effects but also can avoid the placebo effect in training. In this study, the active control group practiced tasks with low WM demand, which were a animal memory task (Wei et al., 2022). We asked participants to complete a 90-trial memory task each day. First, a "+" gaze point appeared in the middle of the screen for 0.3 s. An animal appeared in the middle of the screen, and the memory task was presented for 1,750 ms, followed by nine animals. Participants were asked to recall which animal had appeared before. The specific process is shown in Figure 2.

Outcome Measures

WM Task

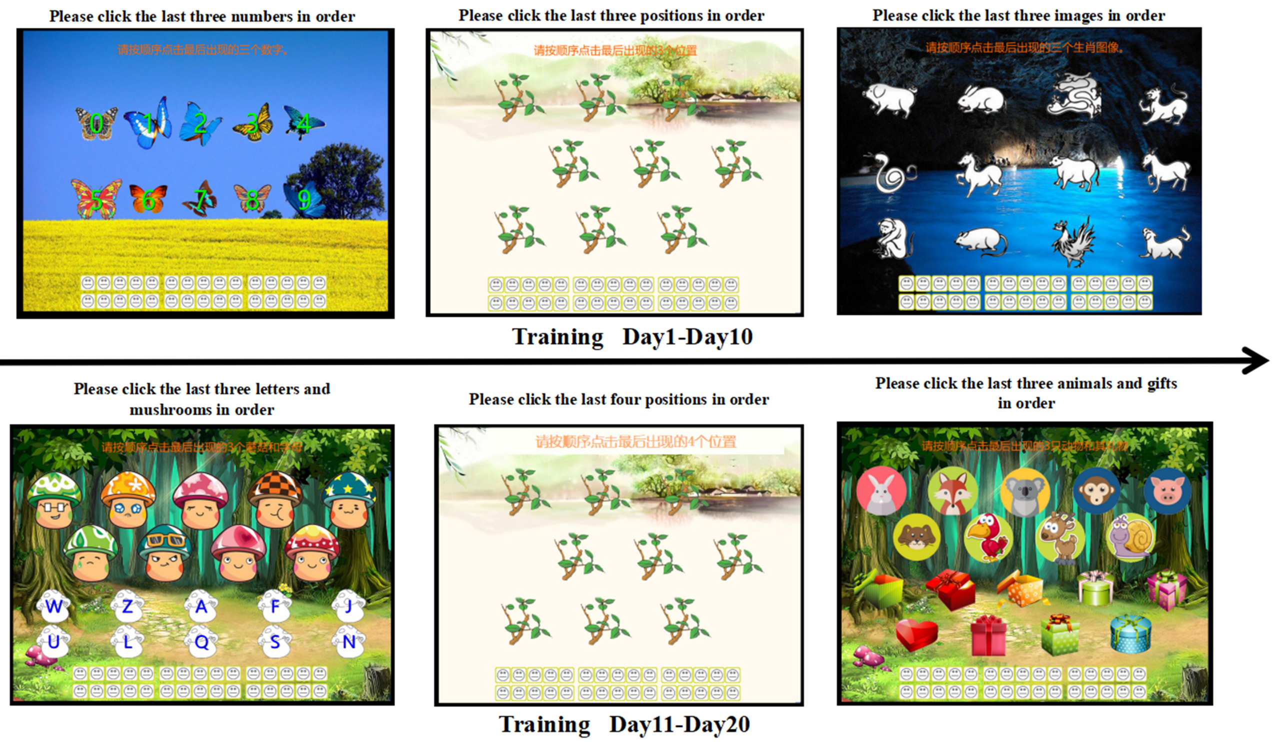
In the pre-, post-, and follow-up tests, the 2-back and 3-back tasks were used to measure the WM ability of the participants. In the 2-back task, participants were asked to compare whether the current number was the same as the previous second number. The 3-back task compared whether the current number was the same as the previous third number. Participants in the training and control groups were counted separately for reaction time (RT) and accuracy (ACC) during the pre-, post-, and follow-up tests.

ER Task

We modified the ER task used in previous studies (Ertl et al., 2013), and participants performed this ER task on the pre-, post-, and follow-up tests. 135 negative images and 45 neutral images (560 × 420 pixels) from the International Library of Emotional Images (Lang et al., 2005) were used as emotional stimulus material (see Part 2 in the online supplemental materials for image numbers). The valence for all neutral pictures was 5.26 ± 0.56; arousal was 4.42 ± 0.75. The valence for all negative pictures was 2.69 ± 0.69; arousal was 5.37 ± 0.63. There were significant differences between negative and neutral pictures in valence, $t(178) = -22.395$, $p < .001$, Cohen's $d = -3.86$, 95% CI [−4.38, −3.33], and arousal, $t(178) = 8.281$, $p < .001$, Cohen's $d = 1.425$, [1.06, 1.79].

The ER task was divided into four task types: two reappraisal conditions (Increase, Decrease) and two control conditions (Look Negative, Look Neutral). Among them, 45 neutral pictures were used for "Look Neutral" and 135 negative pictures corresponded to the three conditions of "Look Negative," "Increase Negative," and "Decrease Negative," respectively. And there were no statistical differences in the valence and arousal of negative pictures in these three conditions. In the "Look Neutral" and "Look Negative" conditions, participants were asked to view the neutral or negative picture attentively and allow themselves to experience any emotional responses. In the "Decrease" condition, which centers on down-regulation of negative emotion, participants were asked to produce a less negative interpretation of the scene shown in the picture, which could be accomplished in a variety of ways, such as by imagining that what was in the picture was an actor's performance or a prop, or by focusing on the positive aspects of the picture. For example, when a picture of an air crash scene appears, focus on the positive aspects in the picture, such as the appearance of an ambulance, which can save many lives. In the "Increase" condition, which centered on upregulation of negative emotions, participants were asked to focus on the negative aspects of the picture, or to imagine that the

Figure 1
The Schematic Diagram of the Running Working Memory Task



Note. See the online article for the color version of this figure.

person in the picture was themselves, or a friend or family member. In addition, during the experiment participants were asked to complete the task strictly following the appropriate instructions, so that regulation remained within the confines of the given scenario and did not replace or alter their emotions by thinking about situations unrelated to the current scenario. This was done to allow participants to regulate their emotions according to the framework of the test.

The experimental flow chart is shown in Figure 3. The fixation "+" was first presented for 2 s, followed by 2 s of instructions (Look, Increase, Decrease), followed by 5 s of picture stimulus presentation and a 500 ms blank screen after the picture disappeared, and finally, participants rated the picture on a scale of 1–9 for valence (how much they liked the picture) and arousal (how intense the picture was) on a scale of 1–9.

Prior to the formal experiment, participants were required to complete a 16-trial practice task in order to fully understand and perform the different ER strategies. The formal experiment was not conducted until it was determined that the participants truly understood and could correctly follow the different instructions for the task. The formal experiment consisted of 180 trials in three blocks (each block has 60 trials, with each condition occurring the same number of times and the order of the trials was randomized within the blocks).

Procedure

Participants arrived at the laboratory and first filled out personal information and informed consent forms, and then completed the 2-back and 3-back tasks. After a short break, an ER task was performed while recording the electroencephalography (EEG).

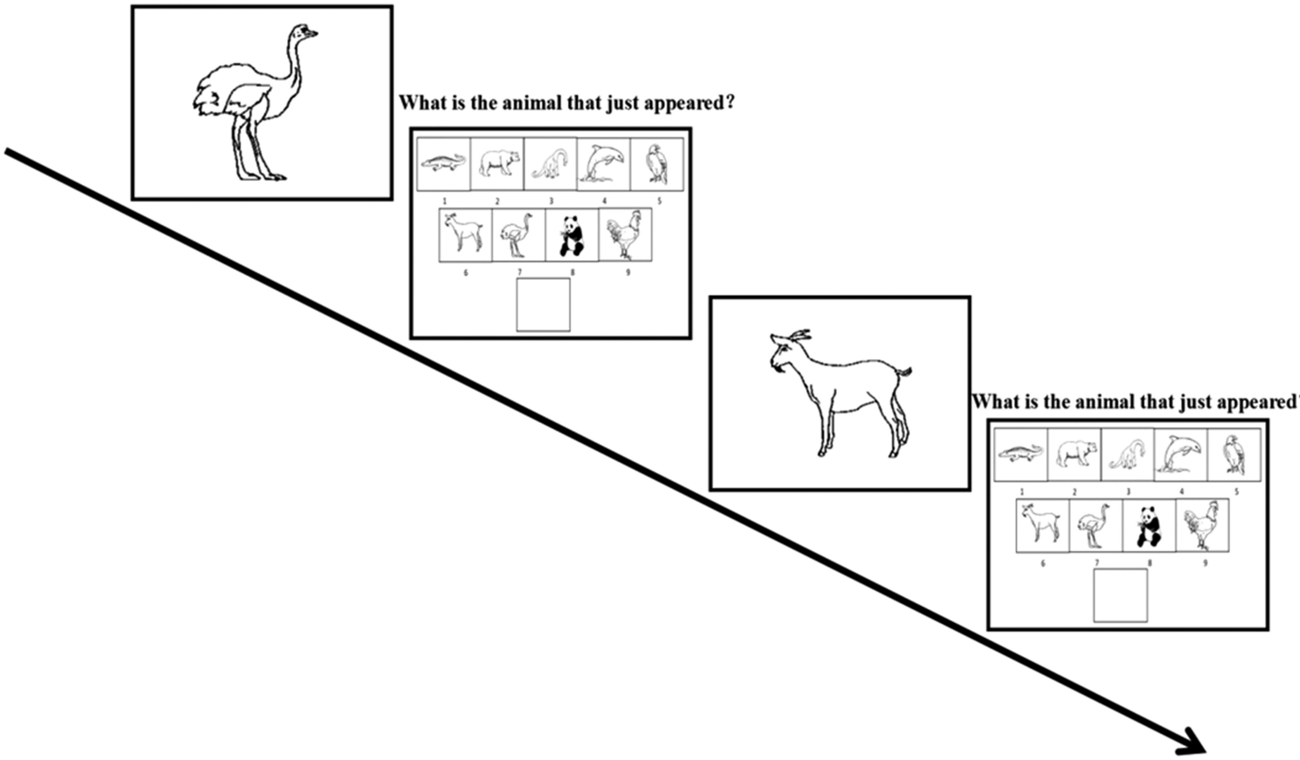
During the training period, 20 days of running WMT (for the training group) and control training (for the control group) were completed in the laboratory. Participants are required to complete the training tasks within 4 weeks. After training, participants complete the 2-back and 3-back tasks as well as the ER task. The follow-up test was administered 3 months after the participants completed the posttest, and the experimental procedures were the same as for the pre- and posttests.

EEG Recording and Analyses

EEG was recorded using a Curry 8-32 conductor recording system in DC mode. The EEG was recorded with each electrode referenced to the ground point (at the midpoint of the FPz and Fz lines), with the vertical electrooculography (VEOG) electrodes placed in the left supraorbital and infraorbital centers, and the horizontal electrooculography (HEOG) electrodes placed in the left and right lateral canthi. The sampling rate of the data was 1,024 Hz, the bandwidth of the recording was 100 Hz for low-pass, and the resistance of all electrodes was kept below 10 kΩ during the experiment.

After acquisition, the data were preprocessed using EEGLAB (Delorme & Makeig, 2004). Specifically, first, the data were re-referenced and the bilateral mastoid was used as the reference electrode; second, the data were low-pass filtered at 30 Hz and high-pass filtered at 1 Hz; then, the bad electrode points were replaced by

Figure 2
The Schematic Diagram of Active Control Training



interpolation, and the bad segments were removed. In addition, other artifacts with amplitudes greater than ±80 μV were automatically excluded. Finally, Eye movement artifacts were corrected using individual independent component analysis (ICA) by removing the corresponding components based on the particular activation curve (Mennes et al., 2010). 96% of the trials were included in further ERP analysis. The data from the four conditions of this study were superimposed and averaged, and the intercepted time period was from −500 ms before the image presentation to 1,000 ms after the image presentation in order to store the results for each of the four conditions.

In the ERP analysis, a baseline correction of −200 to 0 ms was selected with reference to previous studies (Bress et al., 2013). Based on the overall mean waveform and topographic distribution of all subjects participating in this study and previous literature involving LPP as an indicator of ER (Hajcak & Nieuwenhuis, 2006; Pan et al., 2022; Xiu et al., 2018), a time window of 400–1,000 ms (typically early LPP) was selected for LPP analyses, and electrode points of "CP3," "CPz," "P3," "Pz," "P4," "O1," "Oz," "O2" which can reflect the prominent LPP were averaged for further analysis.

Statistical Analysis

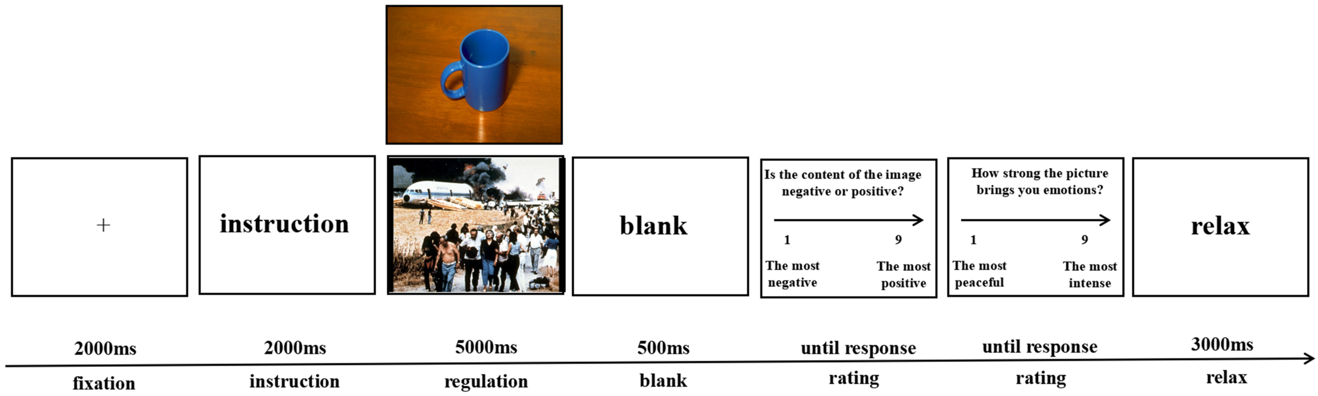
First, for the WM task, we used a two-way ANOVA for 2-back and 3-back performance, with group (training, control) as a between-subjects factor and time (pretest, posttest, follow-up test) as a within-subjects factor.

Second, before training, a two-way ANOVA was conducted with the experimental condition (Increase, Decrease, Look Negative, Look Neutral) as a within-subjects factor and group as a between-subjects factor. To examine whether there were differences between the two groups of participants at the baseline period and whether both were able to follow the instructions accordingly (operant test). The "Look Neutral" condition was used as a baseline for comparison with the other conditions to demonstrate the success of negative picture-induced negative emotion.

Third, to examine the effect of WMT on ER, a three-way ANOVA was conducted on outcome indicators of the ER task (self-reported arousal, self-reported valence, and LPP amplitude). Time (pretest, posttest, follow-up test) and experimental condition (Increase, Decrease, Look Negative) were used as within-subject factors and group as between-subject factors, where a Group × Time interaction would indicate a differential impact of the interventions over time. It should be noted that, with reference to the studies of Pan et al. (2022) and Long et al. (2020), the experimental conditions involved in the analysis of the effects of ER no longer include the "Look Neutral" condition.

Data analysis was performed using the SPSS 22.0 software package, and the failure of the ANOVA sphericity test was corrected by the Greenhouse–Geisser method. Post hoc multiple comparisons were conducted using the Bonferroni test. All statistical tests were two-tailed tests with an α level of 0.05. We also reported a 95% CI for effect sizes and group means for all analyses. Effect sizes were presented as partial eta squared (η_p^2) for ANOVA effects.

Figure 3
The Flow Chart of Emotion Regulation Task



Note. See the online article for the color version of this figure.

Results

Training Progress

For participants in the training group, we recorded their training level and analyzed it as an indicator of training progress. Our results showed that the participants' training performance improved over time (see Figure S1 in Part 3 in the online supplemental materials for details).

For the WM task, the 2-back and 3-back performances of participants in the training and control groups at the pre-, post-, and follow-up tests are shown in Table 1. The results showed that there was no significant Time × Group interaction for both 2-back ACC and RT. However, the Time × Group interaction effect was significant in the 3-back ACC, $F(2, 80) = 3.880$, $p = .025$, $\eta_p^2 = 0.088$, 95% CI [0.006, 0.18], for the training group, the 3-back ACC were significantly higher on both the posttest and the follow-up test than on the pretest, but the difference between the three time points for the control group was not significant (see Part 3 in the online supplemental materials for details).

Table 1
*The Accuracy (%) and the Mean Response Time (ms) of Cognitive Tasks Measured at Each Time Point for the Training and Control Groups (*M ± SD*)*

WM task	Training group ($n = 22$)	Control group ($n = 20$)
2-Back ACC (%)		
Pretest	82.23 ± 13.89	83.41 ± 12.11
Posttest	85.77 ± 14.87	83.55 ± 12.61
Follow-up test	83.00 ± 13.12	82.80 ± 15.23
2-Back RT (ms)		
Pretest	455.86 ± 231.49	422.65 ± 199.96
Posttest	325.68 ± 209.97	343.17 ± 152.78
Follow-up test	315.74 ± 227.47	333.32 ± 138.56
3-Back ACC (%)		
Pretest	84.41 ± 10.78	86.62 ± 7.09
Posttest	91.45 ± 10.85	85.42 ± 11.07
Follow-up test	91.09 ± 9.14	86.40 ± 13.23
3-Back RT (ms)		
Pretest	551.07 ± 296.81	515.61 ± 193.12
Posttest	440.94 ± 263.99	470.02 ± 218.79
Follow-up test	361.61 ± 190.57	410.56 ± 246.89

Note. WM = working memory; ACC = accuracy; RT = response time.

Pretest ER Task Performance

The analysis of pretest data is shown in Figure 4, and the results show that no significant main effects of group were found for arousal, $F(1, 40) = 1.307$, $p = .260$, $\eta_p^2 = 0.032$, valence, $F(1, 40) = 0.474$, $p = .495$, $\eta_p^2 = 0.012$, and LPP amplitude, $F(1, 40) = 0.142$, $p = .709$, $\eta_p^2 = 0.004$, which suggests that the baseline levels of participants in both groups were consistent. In addition, the main effect of these indicators on conditions is significant ($p < .001$), compared to neutral pictures, negative pictures elicited significant negative emotion. Moreover, participants completed both up- and downregulation of negative emotion according to the instruction (see Part 4 in the online supplemental materials for more details on the results). Our results suggest that the experimental manipulation was effective.

Results of ER Task

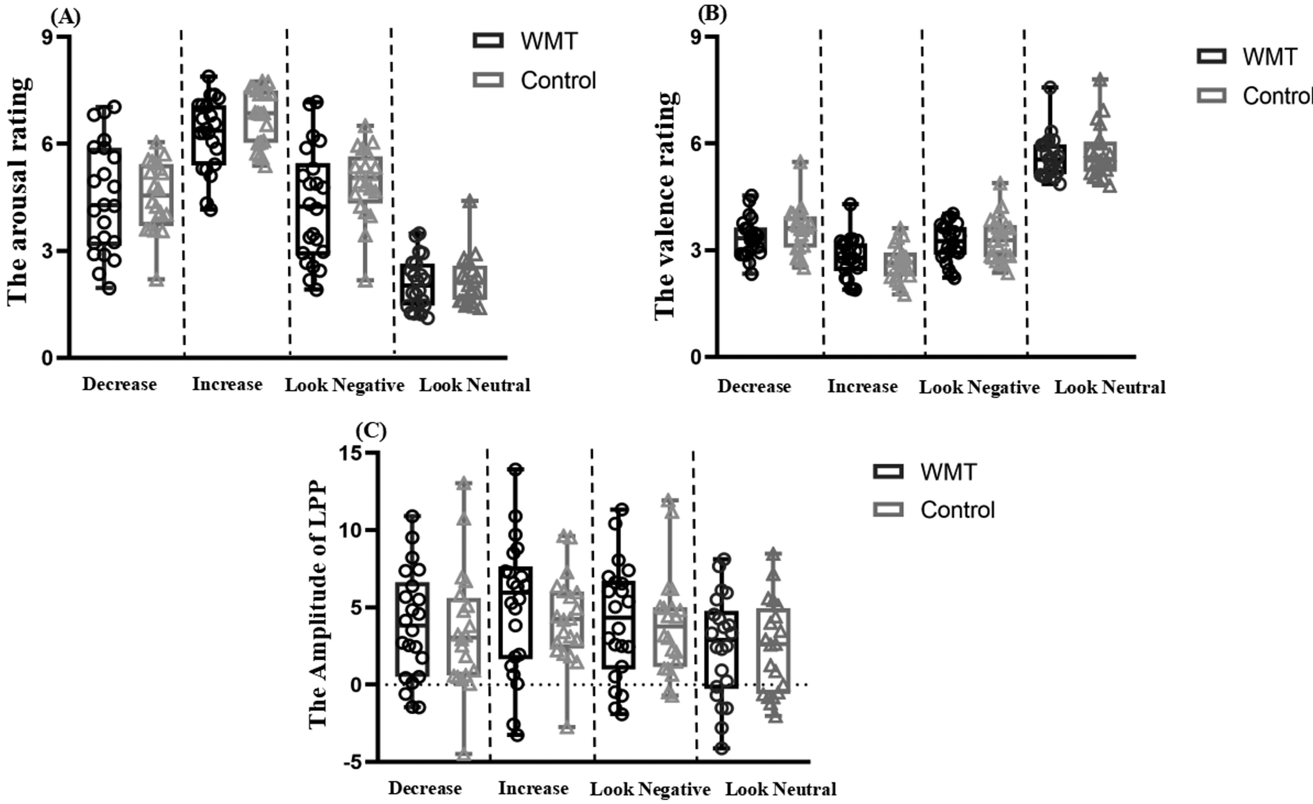
Arousal

The results for arousal are shown in Figure 5A. The Time × Group interaction was significant, $F(2, 80) = 5.149$, $p = .008$, $\eta_p^2 = 0.114$, 95% CI [0.02, 0.22] (as shown in Figure 5B), and for the training group, the difference between pretest and posttest was significant ($p < .05$), with arousal for the posttest ($M = 4.64$, $SE = 0.24$) was significantly lower than that of the pretest ($M = 5.01$, $SE = 0.24$), indicating that participants were less intense in response to the negative stimuli at the posttest; the difference between the pretest and the follow-up test was also significant ($p < .01$), with the arousal of the follow-up test ($M = 4.49$, $SE = 0.24$) was significantly lower than that of the pretest. However, in the control group, there was no significant difference between pre-, post-, and follow-up tests.

The Time × Condition × Group interaction was also significant, $F(4, 160) = 2.600$, $p = .038$, $\eta_p^2 = 0.061$, 95% CI [0.002, 0.11]. We analyzed this interaction separately for each group; for the training group, in the "Decrease" condition, the difference between pretest and posttest was significant ($p < .01$), and arousal was significantly

Figure 4

Performance of Two Groups in the Pre-test Phase on the Emotion Regulation Task



Note. (A) Arousal of the pretest for the training group and the control group. (B) Valence of pretest for training group and control group. (C) LPP amplitude in the pretest for the training group and control group. LPP = late positive potential; WMT = working memory training group; Control = active control group.

lower in the posttest than in the pretest, indicating that the subjects' perceived intensity of the negative stimulus was not as strong in the posttest; the difference between pretest and follow-up test was also significant ($p < .01$), and arousal was significantly lower in the follow-up than in the pretest; but the difference between posttest and follow-up test were not significantly different. The "Increase" condition also showed the same pattern of results as the "Decrease" condition. However, the differences in the pre-, post-, and follow-up tests were not significant in the "Look Negative" condition. For the control group, the differences in arousal in all three phases were not significant in either the "Decrease," "Increase," or "Look Negative" condition.

Valence

The results of the valence are shown in Figure 6A. The Time × Group interaction was significant, $F(2, 80) = 4.546$, $p = .013$, $\eta_p^2 = 0.102$, 95% CI [0.01, 0.20] (as shown in Figure 6B), and for the training group, the difference between pretest and posttest was significant ($p < .001$), with significantly higher valence for the posttest ($M = 3.38$, $SE = 0.12$) than the pretest ($M = 3.12$, $SE = 0.10$), indicating that subjects' pleasure to negative stimuli increased in the posttest; the difference between pretest and follow-up test was also significant ($p < .01$), with follow-up test ($M = 3.32$, $SE = 0.10$) having a significantly higher valence than pretest; no significant difference was found between posttest and follow-up test. In the control group, there was no significant difference between pre-, post-, and follow-up tests.

LPP Amplitude

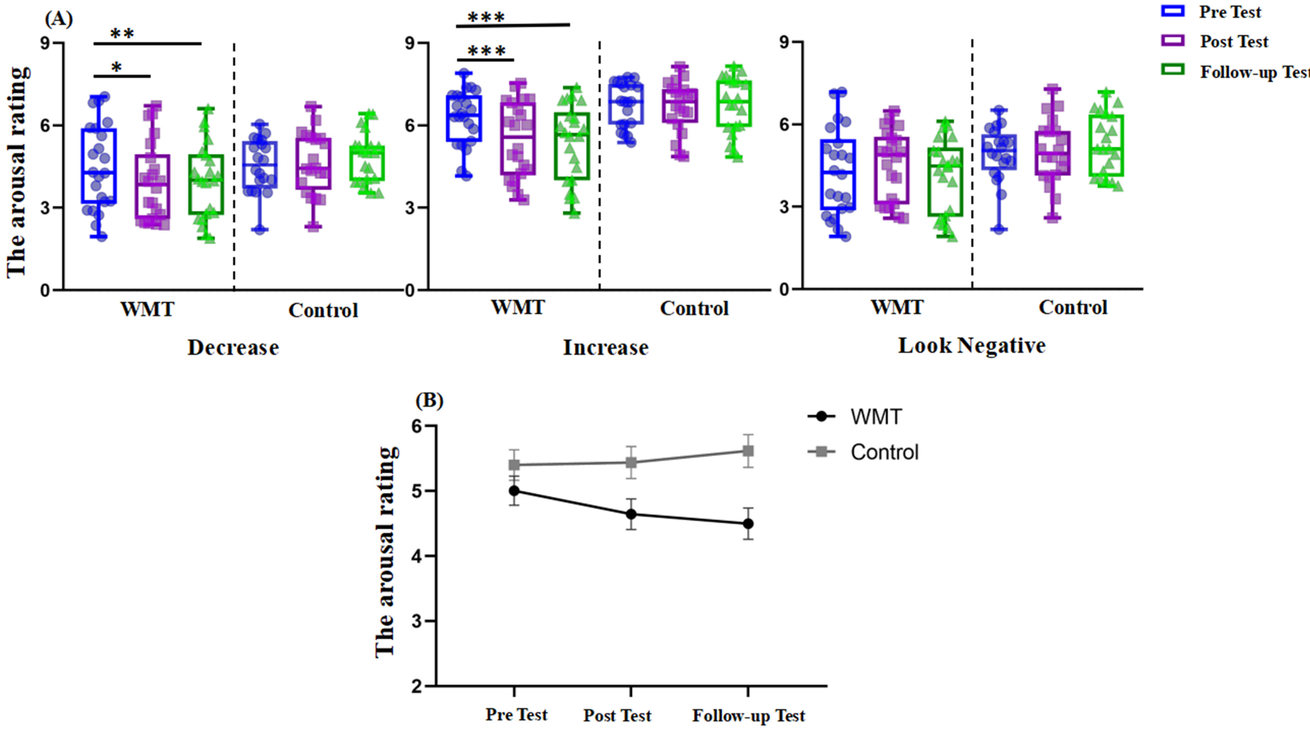
The results for LPP (400–1,000 ms) are shown in Figure 7A. The interaction between time and group was significant, $F(2, 80) = 3.481$, $p = .036$, $\eta_p^2 = 0.080$, 95% CI [0.003, 0.17] (as shown in Figure 7B), for the training group, the difference between pretest and posttest was significant ($p < .01$), with significantly lower LPP amplitude in the posttest ($M = 1.620$, $SE = 0.43$) than in the pretest ($M = 4.37$, $SE = 0.75$), indicating that subjects became better able to regulate emotion in response to stimuli in the posttest; the difference between pretest and follow-up test was also significant ($p < .001$), with significantly lower LPP amplitudes for the follow-up test ($M = 0.953$, $SE = 0.52$) than the pretest; no significant difference existed between posttest and follow-up test. However, in the control group, there were no significant differences between pre-, post-, and follow-up tests. The EEG topography and waveform plots for the training and control groups are shown in Figure 8 (see Part 5 in the online supplemental materials for more details on the results).

Correlation Analysis

For participants in the training group, we first analyzed the correlations between gains on pretest and posttest WM tasks (2-back, 3-back)

Figure 5

Arousal Change From the Emotional Regulation Task in Pre-, Post- and Follow-up Test for Two Groups



Note. (A) Arousal for the training and control group at three time points under different experimental conditions. (B) Changes in arousal from pretest to follow-up test in the experimental and control group. WMT = working memory training group; Control = active control group. See the online article for the color version of this figure.
* $p < .05$. ** $p < .01$. *** $p < .001$.

and gains on ER (LPP amplitude, valence, arousal). Our results showed that in the "Decrease" condition, the gain of self-reported emotional valence was significantly positively correlated with the gain of 2-back ACC ($r = .544$, $p = .009$; as shown in Figure 9A), and marginally correlated with the gain of 3-back RT ($r = .403$, $p = .063$; as shown in Figure 9B); In the "Increase" condition, the correlation between the gain of self-reported emotional valence and the gain of 2-back ACC was marginally significant ($r = .413$, $p = .056$; as shown in Figure 9C). The differences between the other results are not significant (see Part 6 of the online supplementary materials).

For participants in the training group, we also analyzed the correlation between WM task gain and ER gain from the pretest to the follow-up test. Our results found a significant correlation between improvement in self-reported emotional arousal and improvement in RT of the 3-back in the "Increase" condition ($r = .428$, $p = .047$; Figure 9D). In general, the results of the correlation analysis indicated that the more WM capacity enhancement induced by training, the more effective the regulation of negative emotion.

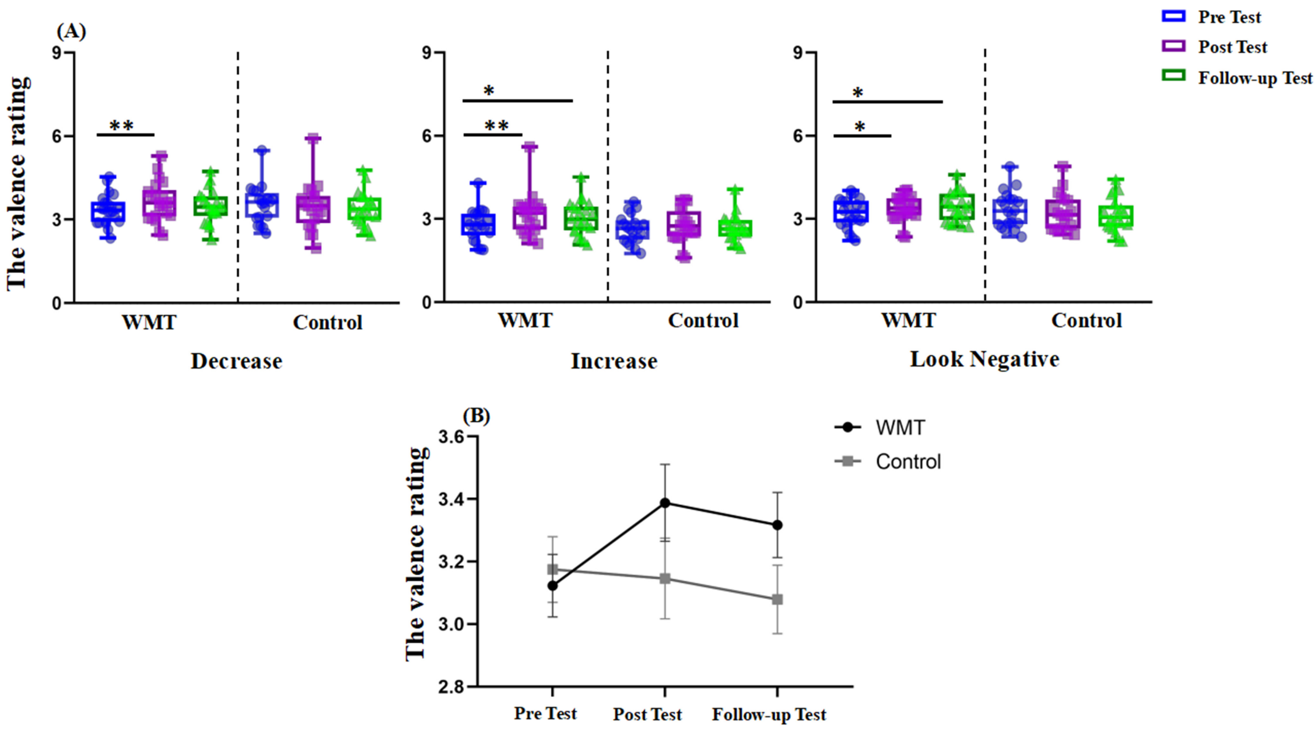
Discussion

The present study explored the effects of WMT on different targets of cognitive reappraisal and how long the effect could persist. Our results showed that after 20 days of WMT in the training group, the regulation of negative emotion was in the direction of reducing the impact of negative emotion compared with the baseline period, regardless of whether it was under upregulated or downregulated reappraisal instruction. Specifically, in the "Increase" and "Decrease" conditions, WMT led to a decrease in self-reported arousal to negative stimuli and an increase in self-reported valence, WMT also led to a significant decrease in LPP amplitude. In our study, arousal was a rating of the intensity of the negative picture, and valence was a rating of the liking of the negative picture, with both lower arousal and higher valence indicating that individuals were better adjusted to negative stimuli on behavioral indicators. In addition, an increase in self-reported valence to negative pictures and a decrease in LPP amplitude were also observed in the "Look Negative" condition. These results suggest that WMT can generally improve the regulation of negative emotion. Our study also found that the improvement in negative ER by training could persist for up to 3 months. The results of the correlation analysis showed that in the posttest, the gain of the WM task in the training group was significantly correlated with the improvement of emotional valence in the "Decrease" condition and marginally correlated with the improvement of emotional valence in the "Increase" condition. In a follow-up test, our results found a significant correlation between gains in WM tasks and improvements in self-reported emotional arousal in the training group in the "Increase" emotion condition. These results suggest that the more WM ability is improved, the better the ability to regulate negative emotion.

Our study first examined the effect of WMT on down- and upregulation of negative emotion. The results showed that participants were more successful in downregulating negative emotion after

Figure 6

Valence Change From the Emotional Regulation Task in Pre-, Post- and Follow-up Test for Two Groups



Note. (A) Valence for the training and control group at three time points under different experimental conditions. (B) Changes in valence from pretest to follow-up test in the experimental and control group. WMT = working memory training group; Control = active control group. See the online article for the color version of this figure.
* $p < .05$. ** $p < .01$.

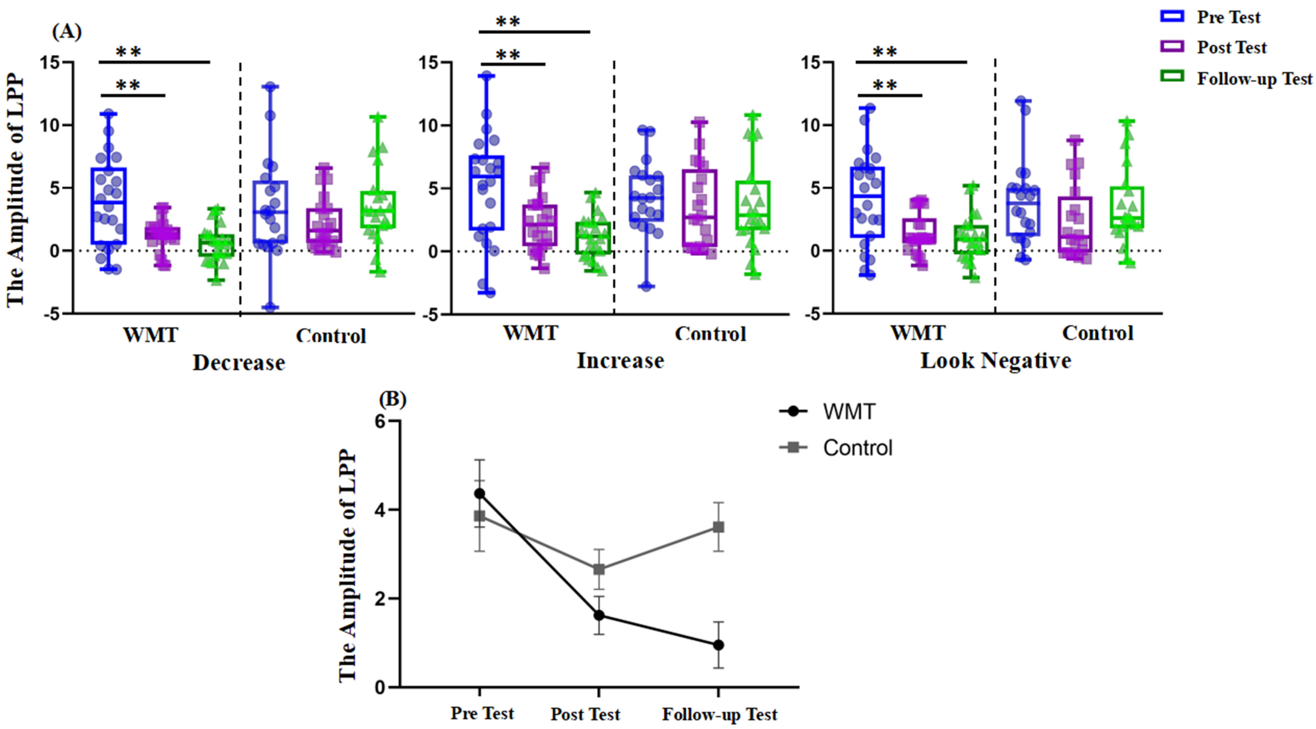
WMT, as reflected by a significant reduction in LPP amplitude, which is consistent with previous findings (Pan et al., 2022; Xiu et al., 2018). We also found improvements from WMT on subjective self-report indicators (valence, arousal), consistent with the findings of Swainston and Derakshan (2021). On the other hand, in the upregulated negative emotion condition, the LPP amplitude, which represents the ability to regulate emotions, significantly decreased after WMT, indicating that participants were regulating the effects of negative emotions rather than enhancing them. Our results suggest that participants' ability to regulate negative emotion was consistently better after the WMT, regardless of whether the goal of cognitive reappraisal was to down- or upregulate negative emotion, and that this effect could persist through the follow-up test.

Could this result be due to the fact that participants did not follow the instructions on ER after training? To rule out this possibility, we performed paired-sample *t* tests for measures of ER (LPP amplitude, self-rated valence, and arousal) in the "Increase" and "Decrease" conditions in both the posttest and the follow-up test (see Part 7 in the online supplemental materials for details). It was found that the LPP amplitude in the "Increase" condition was significantly greater than that in the "Decrease" condition in both the posttest and follow-up test in the training group; the arousal in the "Increase" condition was significantly greater than that in the "Decrease" condition; and the valence of the self-reported in the "Increase" condition was significantly smaller than that in the "Decrease" condition. These results suggest that participants completed the cognitive reassessment task with different goals after training by strictly following the instructions. Could it be that the multiple repeated measures led to lower perceptions of negative emotions in the "Increase" condition after training? However, the control group also completed the pre-, post-, and follow-up tests at the corresponding times, and we did not find any differences between the pretest and follow-up tests in the upregulation of negative emotion; therefore, we also rule out repeated measures as a cause.

We attempted to explain the effect of WMT on upregulation of negative emotion in two ways. On the one hand, we suggest that the current results may be a consequence of competition between salience/defensive neural networks and central-executive networks. In our study, adaptive WMT was a cognitively demanding activity, and performing this task resulted in increased activation of the central-executive network (de Voogd & Hermans, 2022). Correspondingly, the activation of salience/defensive neural networks involved in the amygdala is diminished, which may lead to a general improvement in ER. Our findings are in line with previous research. Previous research has shown that subjective ratings of negative stimuli (Van Dillen et al., 2009) or subjective reports of state anxiety (Balderston et al., 2016) decrease with increasing cognitive load on WM tasks. On the other hand, we have tried to explain the current results in terms of an increase in cognitive resources. There was a significant Time × Group interaction for the 3-back ACC after WMT, with the training group having significantly higher ACC than

Figure 7

LPP (Late Positive Potential) Change From the Emotional Regulation Task in Pre-, Post- And Follow-up Test for Two Groups



Note. (A) LPP amplitude for the training and control group at three time points under different experimental conditions. (B) Changes in LPP amplitude from pretest to follow-up test in the experimental and control group. LPP = late positive potential; WMT = working memory training group; Control = active control group. See the online article for the color version of this figure.
** $p < .01$.

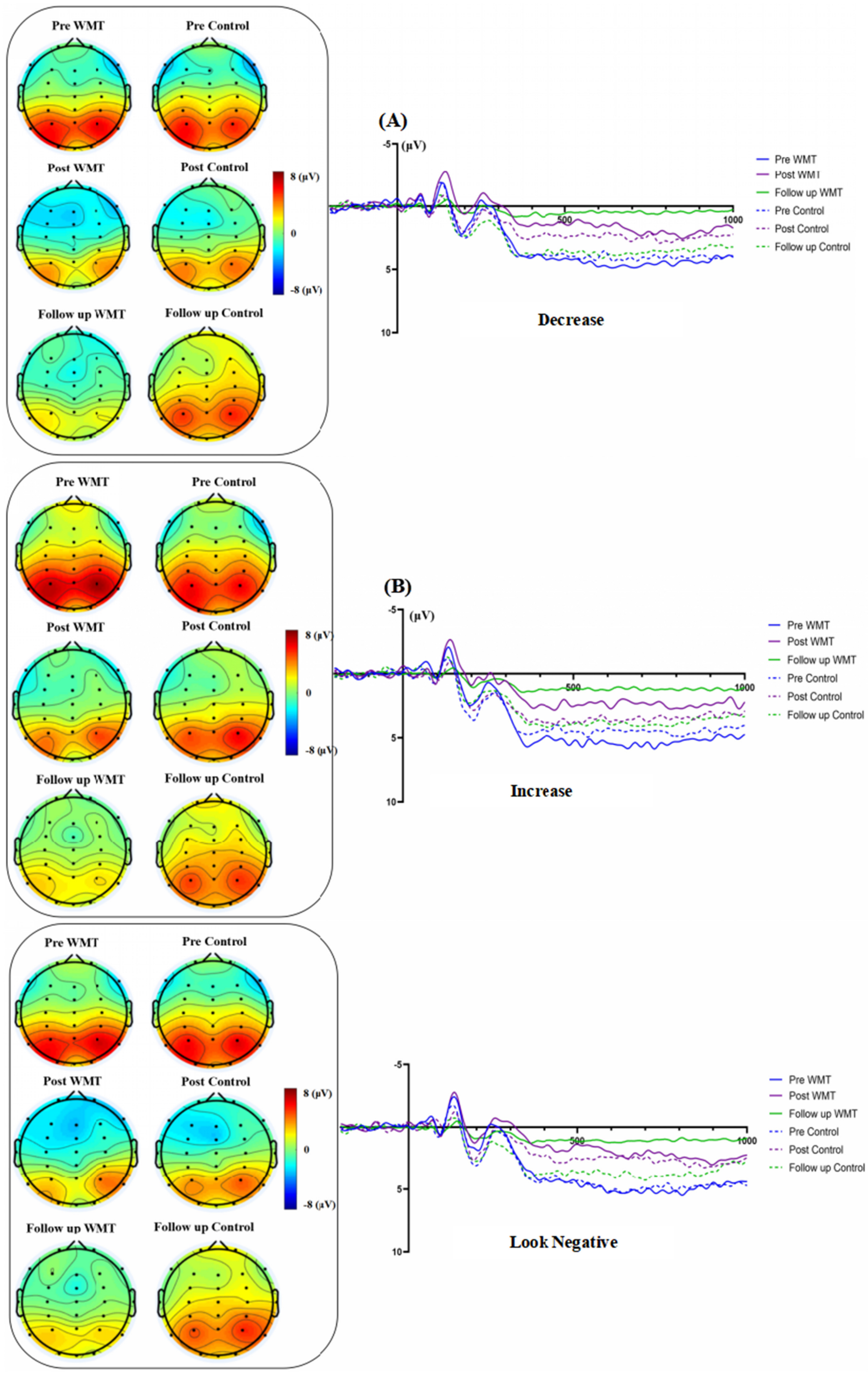
the control group in the posttest and follow-up test, suggesting that the training group's WM capacity was significantly enhanced. Alloway and Alloway (2013) suggest that WM is also a cognitive resource used to keep goals in mind and is responsible for bringing in resources from different parts of the brain and managing incoming information. Increased WM capacity implies that individuals have more cognitive resources available, in which case, individuals' response patterns when upregulating negative emotion may assess all stressful situations as challenges, as described by the BPSM of challenge and threat, and devote current cognitive resources to dealing with such challenges in order to maintain a balance between top-down and bottom-up attention systems (Vine et al., 2016). After training, individuals have more cognitive resources available to cope with the challenges of negative stressful situations. Even under the upregulation conditions, there is a tendency to regulate negative stimuli to maintain one's emotional stability.

Notably, in terms of self-reported valence and LPP amplitude, in addition to the training-induced improvement in negative ER observed in the up- and downregulated negative emotion conditions, we also saw similar effects in the "Look Negative" condition, and this improvement persisted into the follow-up test. Given the stable results in the negative viewing condition, we propose to extend the effect of WMT on ER to a broader scope, that is, WMT leads to a general cognitive enhancement that will help to improve the perception of negative emotions in any kind of negative situation and thus achieve enhanced ER. The same results currently obtained under the three ER instructions also prompted us to think about the nature of enhanced ER. We argue that enhanced ER essentially enhances the sense of control over the bodily arousal brought about by the emotion, bringing it under individual control. As Richey et al. (2012) showed, those with a greater sense of control over fearful emotions have lower anxiety, and this holds true in the area of ER as well. Therefore, whether the task of ER is upregulating, downregulating, or look negative stimuli, what WMT enhances is the sense of mastery over the body's responses in negative emotional situations. When the individual has enough resources to master it, the ultimate goal of ER is governed by the individual's consciousness, which will actively reduce the impact of negative emotions.

Our results also suggest that the effect of WMT on ER is sustained and that this effect can persist for up to 3 months. This is in line with the findings of Hoorelbeke et al. (2016), who showed that the training group showed improvements in cognitive functioning, contemplation of negative emotions, and depressive symptoms both at the end of training and at the 3-month follow-up compared to the control group. Our results are also consistent with the finding that WMT consistently improves mood susceptibility, as found in the Swainston and Derakshan (2018) study, both suggesting that training can achieve a distant transfer effect in terms of emotion. In addition, the current study goes beyond previous studies in that it is the first to find such sustained gains in objective measures of ER, and that the improvement in behavioral measures of ER by training is also sustained. This finding is important because it suggests that adaptive WMT not only has an immediate effect on the improvement of negative emotions, but

Figure 8

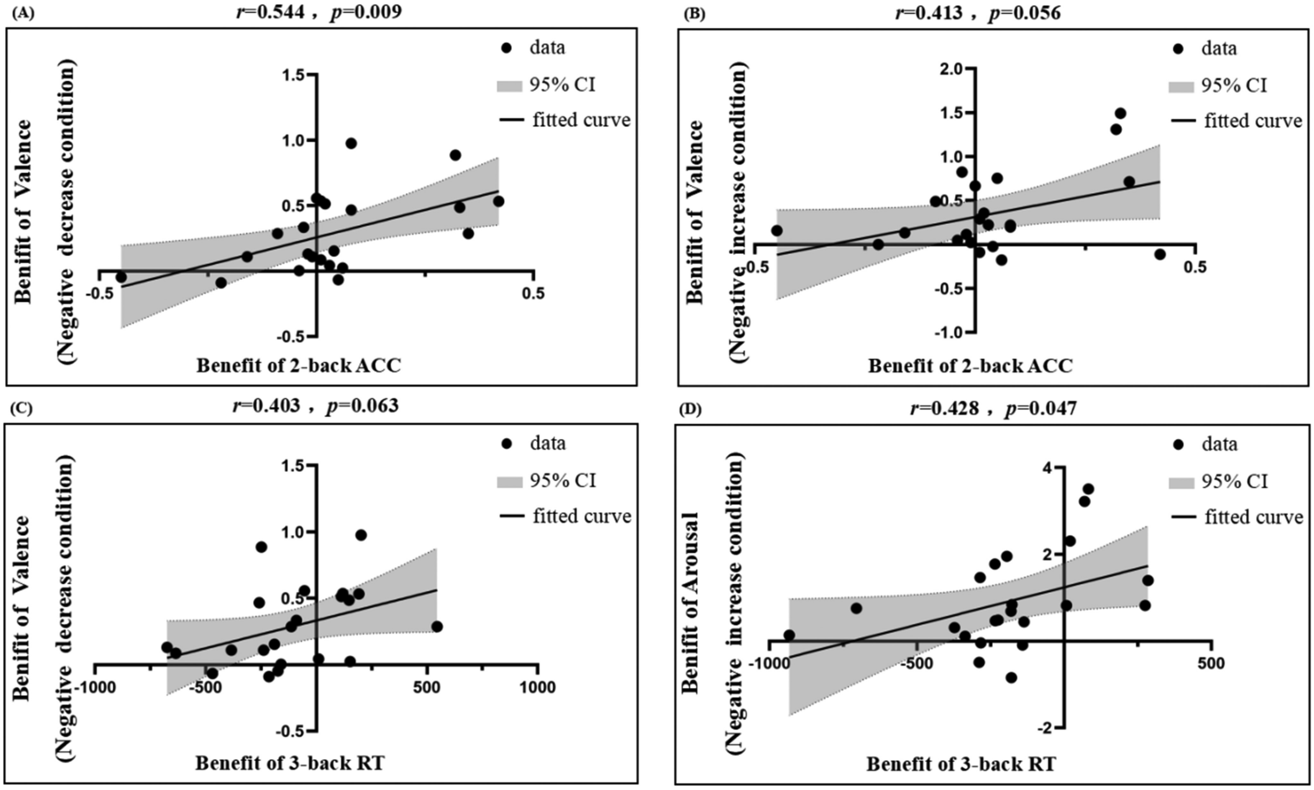
EEG Topography and Waveform Changes From the Emotional Regulation Task in Pre- , Post- and Follow-up Test for Two Groups



Note. (A) Topographic and waveform maps of the training and control group in the "Decrease" condition. (B) Topography and waveforms of the training and control group in the "Increase" condition. (C) Topography and waveforms of the training and control group in the "Look Negative" condition. WMT = working memory training group; Control = active control group. See the online article for the color version of this figure.

Figure 9

Scatter Plots of Changes in WM Performance and Changes in Emotional Regulation Indicators



Note. (A) Correlation of the gain in self-reported emotional valence in the "Decrease" condition with the gain in ACC of the 2-back task for the pretest and posttest. (B) Correlation between the gain in self-reported valence in the "Decrease" condition and the gain in RT of the 3-back task for the pretest and posttest. (C) Correlation of the gain in self-reported valence in the "Increase" condition with the gain in ACC of the 2-back task for the pretest and posttest. (D) Correlation of the gain in self-reported arousal in the "Increase" condition with gain in RT of the 3-back task for pretest to follow-up test. WM = working memory; ACC = accuracy rate; RT = response time; CI = confidence interval.

also allows individuals to sustain these effects over a longer period of time through its effect on neuroplasticity.

Furthermore, our findings provide strong evidence for the far transfer effect of WMT. In previous studies, it may be that differences in training methods, length of training, and participant selection ultimately led to the failure of far transfer (Barkus, 2020; Pergher et al., 2020). In our study, the running memory task we used was a training based on WM refreshing, a process of replacing old information in the WM store with new information. ER can also be seen as a refreshing process, brushing away negative emotions and letting in new good ones (Levens & Gotlib, 2010). The two processes are similar in operation and therefore easier to transfer. In addition, the selection of participants may be an important factor in the effect of transfer. For example, previous studies using healthy older adults as participants did not find that training improved their emotional regulation (Vanderhasselt et al., 2021). In our study, however, we found transfer from the training in the university student participants, and this could be sustained up to the follow-up phase 3 months later. Matysiak et al. (2019) have noted that cognitive training is most effective for individuals with relatively high WM capacity at baseline. As young people have better baseline WM capacity than older people (Alexander et al., 2012; Samson & Barnes, 2013), this may then contribute to the eventual differences in training outcomes.

Our study also has some limitations; for example, WMT did not lead to significant improvements in the 2-back task in terms of the findings, which may be due to the fact that the 2-back task was so easy that participants did not need to exert much effort to complete this task, and thus, even after training, they only used as much cognitive effort to complete the task as they did before training. In addition, in the correlation analysis, there was a significant correlation between the gain in WM ability and behavioral indicators related to ER (arousal, potency), but not between the gain in WM ability and objective indicators of ER. This result is also interpretable in that EEG components reflecting objective indicators of ER reflect changes in the central nervous system and may not correlate well with changes in behavioral outcomes, and future studies could consider the same type of indicators to explore the relationship between changes in ER and gains in WM capacity.

Conclusion

In general, our study found that the effect of WMT on up- and downregulation of negative emotion was consistent, both leading to better regulation of negative emotion, and that this improved effect lasted until the follow-up period after 3 months. Moreover, the training-induced benefit of better regulation in response to negative stimuli was also observed in the training group in the "Look Negative" condition. The consistent effects in the "Increase," "Decrease," and "Look Negative" conditions may suggest that WM updating training leads to an increase in general cognitive ability that is broadly transferable to any of the ER instructions to successfully improve ER.

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