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Looking Inward: Shifting Attention Within Working Memory Representations Alters Emotional Responses

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Abstract

Selective attention plays a fundamental role in emotion regulation. To date, research has examined individuals' use of selective attention to regulate emotional responses during stimulus presentation. In the present study, we examined whether selective attention can be used to regulate emotional responses during a poststimulus period when representations are active within working memory (WM). On each trial, participants viewed either a negative or a neutral image. After the offset of the image, they maintained a representation of it in WM and were cued to focus their attention on either neutral or arousing aspects of that representation. Results showed that, relative to focusing on an arousing portion of a negative-image representation within WM, focusing on a neutral portion of the representation reduced both self-reported negative emotion and the late positive potential, a robust neural measure of emotional reactivity. These data suggest that selective attention can alter emotional responses arising from affective representations active within WM.

Keywords

emotional control, emotions, attention, evoked potentials, short-term memory, emotion regulation, working memory, event-related potentials

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Growing evidence suggests that emotion regulation is crucial for healthy adaptation (Gross, 2007). One particular target for research on emotion regulation is attentional deployment, which involves modifying one's attentional focus in order to influence emotional responding. Findings indicate that directing attention away from emotionally salient features of a situation reduces various aspects of emotional responding, including subjective intensity (Sheppes & Meiran, 2007), peripheral physiology (Urry, 2010), and activation in emotion-generative neural regions, such as the amygdala and insula (Bantick et al., 2002; McRae et al., 2010).

These studies—and, indeed, the bulk of prior research on attentional deployment in the context of emotion regulation—have employed paradigms in which attentional deployment occurs during stimulus presentation. Using two main types of attentional manipulations—shifting gaze (Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009; McLeod, Mathews, & Tata, 1986; Urry, 2010) and loading working memory (WM) with neutral content (MacNamara, Ferri, & Hajcak, 2011; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Sheppes & Meiran, 2007; Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011)—researchers have sought to reduce the processing of an external stimulus by minimizing its encoding into WM. Such an approach nicely models everyday situations in which a person wishes to modify responses to an emotion-eliciting situation unfolding in the environment.

One important limitation of the literature, however, is that it does not address the use of attentional deployment in the many contexts in which emotions are elicited by events after they have been fully encoded into WM. Once encoded into WM, emotional representations often become, and remain, active within WM in the absence of external input. For instance, after one drives past a gory car crash, representations of the scene can continue to be played out within WM, eliciting emotional distress long after the actual scene has passed.

Motivated by emerging research on WM maintenance and the ability to focus attention within WM (Lepsien & Nobre, 2007; Serences, Ester, Vogel, & Awh, 2009), we examined whether attentional deployment can be used to modulate responses arising from emotional events once they have been encoded into WM. We did this by taking advantage of the finding (Hajcak, MacNamara, & Olvet, 2010; Hajcak & Olvet, 2008) that a robust neural marker of emotional reactivity—the

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late positive potential (LPP), a positive-going slow wave in the electroencephalogram (EEG) that begins approximately 300 to 400 ms after stimulus onset—is larger for emotional (relative to neutral) images not only during their presentation (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000) but also after offset, while representations of those images are maintained within WM. More specifically, we probed the LPP during the postimage phase while participants attended to different aspects of an emotional image representation active within WM.

Method

Participants

Twenty-eight Stanford University students (16 males, 12 females) participated in the current study for either course credit (14 participants) or $30 (14 participants). Participants' mean age was 20.14 years, and all participants had normal or corrected-to-normal vision.

Experimental task

One hundred twelve images (56 negative, 56 neutral) were chosen from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and the EmoPicS database (Wessa et al., 2010). The negative and neutral images differed in ratings of normative valence (negative images: $M = 2.18$, $SD = 0.63$; neutral images: $M = 5.10$, $SD = 0.59$) and arousal (negative images: $M = 6.33$, $SD = 0.65$; neutral images: $M = 3.01$, $SD = 0.68$). The images in each category were divided into two separate 28-image sets, which we equated for both valence and arousal (all $ps > .35$). Assignment of image set to condition was counterbalanced across participants.

The trial structure is illustrated in Figure 1. Participants started each trial by pressing the space bar. First, a white fixation cross was presented in the center of a black screen for 2,000 ms. This was followed by either a negative or a neutral image for 1,500 ms. For this initial presentation, participants had been instructed to simply attend to the image and respond naturally. Then, two circles (each of a different color) were overlaid on different areas of the image for 1,500 ms. For neutral images, the two circles highlighted distinct neutral portions of the image. For negative images, one circle highlighted an arousing portion, whereas the other circle highlighted a neutral portion. (Circle color was not linked to emotion type.) For this phase of the trial, participants had been asked to focus on what was contained within each circle. This phase was followed by a black screen lasting 750 ms (WM retention interval), during which participants had been instructed to maintain an internal representation of the full image, including the content of both circles, in WM. Next,

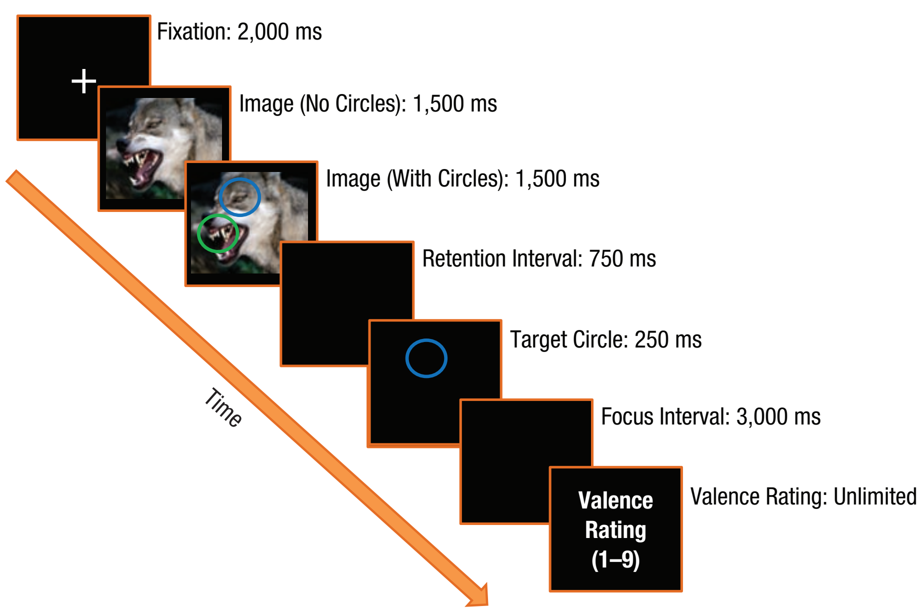

Fig. 1. Illustration of the trial structure. After an initial fixation period, an image (either negative or neutral) appeared on-screen for 1,500 ms. Then, two circles were overlaid on the image for 1,500 ms. For negative images (as shown here), one circle highlighted a neutral portion, whereas the other circle highlighted an arousing portion. For neutral images, both circles highlighted neutral portions. The image then disappeared, leaving a black screen for 750 ms, during which participants held the full image in working memory. Then, one of the circles was presented briefly for 250 ms. In the subsequent 3,000-ms interval, participants had to focus their attention on the portion of the image that had previously been contained within the target circle. Participants then rated how pleasant or unpleasant they felt.

one of the two circles was presented against a black screen for 250 ms. This target circle was always presented in the same spatial location as in the preceding image. This interval was followed by a black screen lasting 3,000 ms (WM focus interval). For this interval, participants had been instructed to shift their attention within the image representation to the content that had previously been contained within the target circle and to visualize that portion of the image representation as vividly as possible. Finally, participants rated how pleasant or unpleasant they were currently feeling on a scale from 1 (*pleasant*) to 9 (*unpleasant*), using the Self-Assessment Manikin (Lang, 1980).

The task consisted of 112 trials, divided into seven blocks of 16 trials each. Twenty-eight trials in each of four conditions were presented: the neutral-image/neutral-focus A, neutral-image/neutral-focus B, negative-image/neutral-focus, and negative-image/arousing-focus conditions. The neutral-image/neutral-focus A and neutral-image/neutral-focus B conditions were functionally identical: Each involved attending to a neutral portion of a neutral image, but they differed in which of the two circles within each neutral image served as the target circle. In the negative-image/neutral-focus condition, the target circle was located in a neutral portion of a negative image, and in the negative-image/arousing-focus condition, the target circle was located in an arousing portion of a negative image. Trials within each of the four conditions were presented in randomized order, with four trials from each condition in each block.

Procedure

After giving informed consent, participants were guided through several practice trials. During practice, the experimenter ensured that participants were successfully attending to the content within both circles when the image with overlaid circles was presented and that they were able to focus on the image content previously occupied by the target circle during the WM focus interval.

Continuous EEG recordings were made using SynAmps amplifiers (Neuroscan, Charlotte, NC) and digitized with Scan 4.3 software (Neuroscan, Charlotte, NC). Recordings were obtained with standard Ag-AgCl electrodes from 22 sites on the scalp; electrodes were placed according to the 10-20 system. AFz served as the ground, and Pz as the on-line reference. The electrooculogram (EOG) from eye blinks was recorded from sites 2 cm below and above the right eye. The EEG signal was recorded in DC mode and sampled at a rate of 500 Hz. Impedance levels were kept below 5 kΩ.

Data reduction and analysis

Preprocessing was conducted off-line using AVG_Q (Feige, 1999). EEG data were first corrected for eye-blink artifacts using the procedure devised by Gratton, Coles, and Donchin (1983). Single-trial EEG epochs were extracted for a period beginning 400 ms before image onset and continuing for the entire duration of the trial until onset of the valence-rating screen (a total duration of 7,000 ms from image onset). Next, all activity was rereferenced to the average of the left and right mastoids, and low-pass filtered at 20 Hz. Trials containing excessive physiological artifacts (i.e., voltages exceeding 150 μV) were discarded; 88% of the original trials were left for analyses. The resulting event-related potentials (ERPs) were baseline corrected using the average activity in the 400-ms window immediately preceding image onset. On the basis of prior research indicating that the LPP is maximal at central parietal sites (see Hajcak et al., 2010, for a review), we quantified the LPP as the average signal amplitude across seven sensors within the central parietal region (Pz, CPz, Cz, CP1, CP2, P3, and P4).

Results

Manipulation checks

We first sought to ensure that our stimuli modulated the LPP in the predicted direction. We therefore analyzed the LPP in the 400- to 1,500-ms window (i.e., during the interval in which the image was presented without circles). Consistent with prior research (Cuthbert et al., 2000; Schupp et al., 2000), planned contrasts showed that both negative-image conditions generated larger LPPs than both neutral-image conditions (all ps < .001). There were no differences in LPPs either between the two negative conditions or between the two neutral conditions (both ps were nonsignificant).

We then examined whether the LPP was modulated by the type of image representation maintained within WM during the postimage WM retention interval (the 3,000- to 3,750-ms window). On the basis of previous findings (Hajcak et al., 2010; Hajcak & Olvet, 2008), we predicted that maintaining representations of negative images within WM would generate larger LPPs than would maintaining representations of neutral images. Planned contrasts revealed that, as expected, maintaining images in both negative conditions elicited larger LPPs than maintaining images in both neutral conditions (all ps < .001). No differences were found either between the two negative conditions[1] or between the two neutral conditions (both ps were nonsignificant).

Primary analyses

We examined whether deploying attention to different aspects of an image representation within WM also modulated the LPP. In particular, we predicted that focusing on a neutral aspect of a negative-image representation would reduce the LPP relative to focusing on an arousing aspect. We therefore examined the LPP during the postimage WM focus interval in the 4,500- to 7,000-ms time window.[2] Planned contrasts revealed that the negative-image/arousing-focus condition elicited a larger LPP than both neutral-image/neutral-focus conditions (both ps < .025). As

Table 1. Mean Late Positive Potential (LPP) Amplitudes (in Microvolts) During Three Time Windows and Mean Self-Reported Ratings of Unpleasantness

	Condition			
Variable	Negative image/ arousing focus	Negative image/ neutral focus	Neutral image/ neutral focus A	Neutral image/ neutral focus B
LPP: display of image without circles (400–1,500 ms)	8.22 (4.12)	7.83 (4.12)	3.21 (4.03)	2.71 (4.38)
LPP: WM retention interval (3,000–3,750 ms)	6.66 (8.36)	6.35 (9.05)	2.82 (7.66)	2.99 (8.53)
LPP: WM focus interval (4,500–7,000 ms)	6.14 (11.47)	3.56 (12.70)	3.27 (12.00)	3.10 (11.79)
Self-reported unpleasantness	6.89 (0.76)	5.84 (0.94)	4.40 (0.89)	4.44 (0.87)

Note: Standard deviations are given in parentheses. WM = working memory.

hypothesized, the LPP was decreased in the negative-image/neutral-focus condition relative to the negative-image/arousing-focus condition (p < .01). No difference was observed between the negative-image/neutral-focus condition and both neutral-image/neutral-focus conditions (both *p*s were nonsignificant). See Table 1 for LPP means at three time windows, and see Figure 2 for grand-average ERPs in each of the four conditions.

We also examined whether participants' self-reported unpleasantness was modulated by where attention was deployed during the postimage WM focus interval. Planned contrasts showed that unpleasantness ratings were higher in the negative-image/arousing-focus condition relative to both neutral-image/neutral-focus conditions (both *p*s < .001). Moreover, unpleasantness ratings were lower in the negative-image/neutral-focus condition relative to the negative-image/arousing-focus condition (p < .001). Diverging from the pattern obtained with the LPPs, however, results for unpleasantness ratings revealed that the negative-image/neutral-focus condition elicited greater unpleasantness than both of the neutral-image/neutral-focus conditions (both *p*s < .001). See Table 1 for mean unpleasantness ratings in the four conditions.

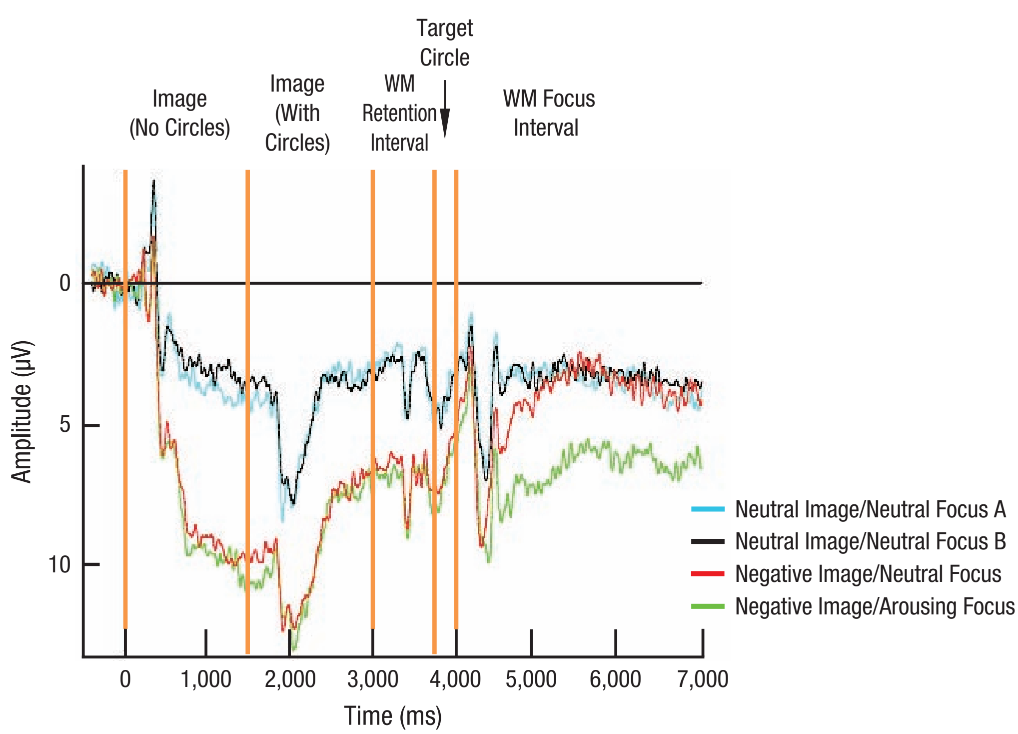

Fig. 2. Grand-average event-related potentials in the four conditions. Positive voltage is plotted downward. WM = working memory.

Discussion

In the present study, we examined whether shifting attention to more or less emotional aspects of representations active within WM would modulate neural and self-reported measures of emotional response. Results showed that relative to focusing on a highly arousing aspect of a negative-image representation within WM, focusing on a more neutral aspect substantially reduced both the LPP, which is a robust neural metric of emotional reactivity, and self-reported unpleasantness ratings. These results suggest that attentional deployment can be an effective means of emotion regulation even after emotional events have been encoded into WM.

Extensive research has shown that emotional events automatically capture attention (see Compton, 2003, for a review). Furthermore, findings from the attentional-blink paradigm suggest that emotional stimuli have preferential access into WM and can be encoded into WM even when they are task irrelevant (Arnell, Killman, & Fijavz, 2007). This raises the possibility that using attentional deployment to prevent the encoding of emotional stimuli into WM may prove challenging in daily life. Nonetheless, our findings suggest that attentional deployment can still be used to powerfully regulate emotion even after events have been fully encoded into WM.

Focusing on a neutral part (relative to an arousing part) of a negative image representation reduced the LPP to the level of focusing on a neutral part of a neutral image representation, but did not reduce self-reported unpleasantness to that extent. Several factors could have contributed to this divergence. First, self-report ratings may have been vulnerable to demand effects, such as the expectation that one should feel unpleasant after viewing negative images. Second, self-report measures depend on an ability to accurately appraise one's emotional state, whereas neural measures such as the LPP do not.

In the present study, we examined attentional deployment applied to visual representations within WM. This aim was partly motivated by the fact that visual representations within WM are both potent and pervasive elicitors of emotion. For instance, a source of much distress in posttraumatic stress disorder is the recurrence of intrusive mental images from a previously experienced traumatic event (Hackmann, Ehlers, Speckens, & Clark, 2004). Thus, examining how attention can regulate emotions generated through active visual WM representations is critical.

The present study suggests a number of future directions. First, although the role of mental imagery in cognition is a source of continuing debate (see Kosslyn, Thompson, & Ganis, 2006, for a review), not all representations active within WM have a visual component. For instance, when one recalls a hurtful comment that a friend has made, the representations that become active within WM are likely to be nonvisual. Moreover, the mechanisms by which attention can be deployed to focus on different aspects of visual and nonvisual representations may differ. In the case of visual representations, we have assumed that attention can be selectively deployed to different spatial locations (Kuo, Rao, Lepsien, & Nobre, 2009). When a representation is nonvisual, however, selective attention will likely not depend on spatial deployment. Thus, a key extension of this study would be to examine attentional deployment in the context of regulating emotions elicited by different types of WM representations.

Moreover, in the present study, we examined how attention can be deployed to different features within a given emotional representation in WM. We argue that this is distinct from deploying attention away from a WM representation to other unrelated tasks. As an example of the latter, a previous study (Kross & Ayduk, 2008) showed that performing a distracting task (i.e., focusing on unrelated neutral sentences) after recalling negative autobiographical memories reduces self-reported negative emotion. It remains to be examined whether deploying attention within emotional WM representations has consequences different from those of deploying attention away from such representations.

Because we used a sample of healthy participants in the present study, another future direction would be to examine attentional deployment within WM in individuals with certain forms of psychopathology. A large body of work has delineated how specific processes underlying attention during stimulus presentation—such as disengagement from an emotional stimulus—are altered in individuals with anxiety (Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001). It remains possible that core features of affective disorders—in particular, rumination and chronic worry—arise at least in part from failures to flexibly deploy attention to different aspects of representations active within WM (Gotlib & Joormann, 2010; Joormann & Gotlib, 2008).

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Notes

1. The finding that LPPs in the two negative-image conditions did not differ during the WM retention interval (p = .59) or during the preceding presentation of the images with overlaid circles (p = .57) suggests that LPPs in these conditions did not differ during image encoding.
2. We coded the LPP starting at 4,500 ms because inspection of the waveforms suggested that target-circle onset elicited a separate ERP in the 4,000- to 4,500-ms window. Predicted effects were significant within the entire 4,000- to 7,000-ms range.

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