NeuroImage 87 (2014) 276–286

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Brain systems underlying attentional control and emotional distraction during working memory encoding

Maryam Ziaei [a,*], Nathalie Peira [b,c], Jonas Persson [c,d,e,**]

[a] School of Psychology, The University of Queensland, St Lucia QLD 4072, Australia
[b] Department of Psychology, Uppsala University, Box 1225, 751 42 Uppsala, Sweden
[c] Department of Psychology, Stockholm University, 106 91 Stockholm, Sweden
[d] Umeå Center for Functional Brain Imaging (UFBI), Sweden
[e] Aging Research Center (ARC) at Karolinska Institute and Stockholm University, Gävlegatan 16, 113 30 Stockholm, Sweden

ARTICLE INFO

Article history:
Accepted 18 October 2013
Available online 31 October 2013

Keywords:
fMRI
Emotion
Amygdala
Working memory
Emotional distraction
Interference control
Selective attention
Top-down
Bottom-up
Fronto-parietal
Default-mode

ABSTRACT

Goal-directed behavior requires that cognitive operations can be protected from emotional distraction induced by task-irrelevant emotional stimuli. The brain processes involved in attending to relevant information while filtering out irrelevant information are still largely unknown. To investigate the neural and behavioral underpinnings of attending to task-relevant emotional stimuli while ignoring irrelevant stimuli, we used fMRI to assess brain responses during attentional instructed encoding within an emotional working memory (WM) paradigm. We showed that instructed attention to emotion during WM encoding resulted in enhanced performance, by means of increased memory performance and reduced reaction time, compared to passive viewing. A similar performance benefit was also demonstrated for recognition memory performance, although for positive pictures only. Functional MRI data revealed a network of regions involved in directed attention to emotional information for both positive and negative pictures that included medial and lateral prefrontal cortices, fusiform gyrus, insula, the parahippocampal gyrus, and the amygdala. Moreover, we demonstrate that regions in the striatum, and regions associated with the default-mode network were differentially activated for emotional distraction compared to neutral distraction. Activation in a sub-set of these regions was related to individual differences in WM and recognition memory performance, thus likely contributing to performing the task at an optimal level. The present results provide initial insights into the behavioral and neural consequences of instructed attention and emotional distraction during WM encoding.

Introduction

The ability to attend to relevant stimuli and inhibiting distracting information is at the core of most cognitive processes. There is physiological evidence that attention can affect the perceptual and post-perceptual stage visual stimulus processing (Gazzaley and Nobre, 2012), and there is evidence that the capacity to focus our cognitive resources on goal-relevant information influences working memory performance (Kane et al., 2007). Moreover, it has been proposed that working memory (WM) can be viewed as the active maintenance of attention to information important for ongoing behavior (e.g. Awh and Jonides, 2001). Indeed, it is well established that selective attention results in increased behavioral performance in a diversity of perceptual (e.g. Posner et al., 1980) and WM (Gazzaley et al., 2005a) tests. A behavioral advantage from selectively attending to task-relevant information is thought to result from reduced interference from distracting information in a limited-capacity system (Gazzaley et al., 2005a; Hasher et al., 2007; Vogel et al., 2005).

The process of attentional regulation of brain activation is known as top-down modulation (Duncan et al., 1997; Fuster, 1990; Gazzaley et al., 2005b; Miller and Cohen, 2001). Top-down modulation provides bias signals to other brain structures, may enhance memory by supporting effective encoding of task-relevant information (Ploner et al., 2001; Rainer and Miller, 2000), and has been related to enhanced neural responses to task-relevant information, and reduced activity to irrelevant information in sensory cortical regions (Desimone and Duncan, 1995). Functional connectivity analyses have also shown that visual cortical regions selectively involved in processing task-relevant information are coupled with a fronto-parietal attentional network, while regions processing irrelevant information are functionally connected with default-mode regions (Chadick and Gazzaley, 2011).

Emotion can influence many different aspects of cognition and behavior, and tend to capture attention more easily than non-emotional stimuli (Vuilleumier, 2005). Interaction between emotional and cognitive processes occurs at multiple levels of processing and across many different emotional contexts and cognitive tasks. With regards to

* Corresponding author.
** Correspondence to: J. Persson, Aging Research Center (ARC) at Karolinska Institute and Stockholm University, Gävlegatan 16, 113 30 Stockholm, Sweden.
E-mail addresses: maryamziae@gmail.com (M. Ziaei), jonas.persson.1@ki.se (J. Persson).

1053-8119/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.neuroimage.2013.10.048

episodic memory, it has been demonstrated that positive and negative emotions affect memory performance, with emotionally salient information typically being remembered more easily compared to neutral information (Anderson et al., 2006; Ashby et al., 1999; Kensinger, 2004; LaBar and Cabeza, 2006). Much less is known about the relation between emotion and WM. Recent investigations have found that emotional distraction during a WM task reduces performance (Dolcos and McCarthy, 2006). This behavioral effect has been shown to be related to enhanced activation in brain regions involved in emotional processing, along with decreased activity in brain regions associated with active maintenance of relevant information in WM (Dolcos and McCarthy, 2006). Emotional stimuli may thus affect goal-directed behavior by either enhancing or disrupting task-relevant processes. Despite known effects of emotion on working memory, little is known about how attention to task-relevant emotional stimuli, while avoiding irrelevant items impacts memory performance. Moreover, it is not known whether such experimental manipulation is associated with modulation of activation in a task-relevant brain circuitry.

The purpose of the present study was to investigate the neural and behavioral underpinnings of attending to task-relevant emotional stimuli while ignoring irrelevant stimuli, during working memory encoding. We adapted a previously used WM task (Gazzaley et al., 2005a,b) to include an instruction to direct attention to emotional information during the encoding phase, and ignore emotional or neutral information during the encoding phase. The adaptation of the task allowed for manipulation of the emotional content of both the attended (positive or negative), and distracting (positive/negative or neutral) stimuli within the same task. We examined if instructed attention during emotional working memory encoding resulted in (i) increased working memory and recognition memory performance and (ii) increased and/or decreased activation in task related and content-specific regions, and (iii) if activation during instructed attention could predict working memory and off-line recognition memory performance. Finally, we also aimed at (iv) identifying regions specifically involved in ignoring task-irrelevant emotional compared to neutral distractors.

We hypothesized that instructed attention to emotion during WM encoding would enhance performance compared to passive viewing, and also elicit activation in a fronto-parietal network implicated in selective attention to particular aspects of incoming sensory information. We further hypothesized that fronto-striatal regions involved in cognitive control in order to cope with emotional distraction would be engaged when participants were asked to ignore task-irrelevant emotional compared to neutral distractors during WM encoding.

Methods

Participants

Sixteen university students (8 females; age range = 23–30 years) participated in the study. Two participants' behavioral and neural data were removed from analysis due to technical problems during fMRI scanning. All participants were right-handed and Swedish speakers, and had no history of neurological or psychiatric problems. All participants were screened for claustrophobia, neurological and psychiatric medications, and MRI contraindication, and all had normal or corrected to normal vision using scanner compatible glasses or contact lenses. All participants took part in two separate test sessions; one for behavioral assessment, and one for the fMRI scanning session. Informed consent was obtained from all participants. The investigation was approved by the Ethics Committee in Stockholm. Participants were paid 800 SEK for their participation.

Materials

Seven hundred eighty six pictures were drawn from the International Affective Pictures Systems (IAPS; Lang et al., 2008). Of these pictures, 312 were rated as negative (valence: M = 2.83, SD = 1.7, arousal: M = 5.54, SD = 2.17), 312 as positive (valence: M = 6.79, SD = 1.73; arousal: M = 4.83, SD = 2.3), and 162 as neutral (valence: M = 4.87, SD = 1.26; arousal: M = 2.79, SD = 2.0). All pictures were in color and were adjusted to a resolution of 600 × 800 pixels for presentation in the scanner.

Procedure

Psychological tests

The participants first completed a health screening over the telephone to ensure their suitability for the study. The study consisted of two separate sessions: first a behavioral pre-testing, and second a fMRI scanning session with behavioral off-line post-testing. The behavioral testing took place at the Psychology Department of Stockholm University, and the fMRI scanning and off-line behavioral testing took place at the MRI facility at the Karolinska hospital on a separate day. During behavioral pre-testing, participants completed the color–word stroop test, and the operation span working memory task. They also received instructions, and performed practice runs of the scanner task in preparation for the scanning session. Participants also performed practice runs of the scanner task immediately prior to the scanning session on the scanning day. Before and after scanning, participants completed the PANAS questionnaire.

Scanner task

In this study we used a modified emotional version of a visual delay recognition paradigm that previously has been used to investigate attentional modulation in WM (Fig. 1; Chadick and Gazzaley, 2011; Gazzaley et al., 2005a). The task was composed of an attention instruction (attend negative/positive; 5000 ms), three sequential screens each composed of a pair of target and non-target pictures (encoding; 2500 ms each separated by a 500 ms fixation cross), a fixation cross (maintenance; 4000 ms), and finally a working memory probe (retrieval; 2000 ms). The inter-trial interval (ITI) had a variable length (42% ITIs of 1.5 s, 28% ITIs of 3 s, 14% ITIs of 4.5 s, 12% ITIs of 6 s, and 4% ITIs of 7.5 s), allowing for an independent estimation of the BOLD response on a trial-by-trail basis. Five conditions were included in this study; (1) attend negative pictures/ignore neutral pictures, (2) attend negative pictures/ignore positive pictures, (3) attend positive pictures/ignore neutral pictures, (4) attend positive pictures/ignore negative pictures, and (5) passively view the pictures included in the target set (Fig. 1). During encoding, the pictures were pairs of either: negative and positive, negative and neutral, positive and negative or positive and neutral pictures depending on the condition. For retrieval, an emotional picture was presented (with negative or positive valence depending on the condition). Participants were instructed to press with their index finger if the presented picture on the memory probe matched any of the previously presented pictures, and press with their middle finger if the probe did not match any of the previously presented pictures. All responses were collected using a scanner compatible response box (Lumitouch, Inc.). For each condition, participants performed 20 trials in four different runs (5 in each run) in two separate sessions. The order of conditions was counterbalanced.

Prior to the WM task, a localizer task was included that consisted of blocks of positive, negative, and neutral pictures that lasted for 16000 ms each. Eight blocks of each positive, negative, and neutral pictures were presented, with a total of 24 blocks. Between each block of pictures, a fixation cross was presented for 16000 ms. Participants were instructed to passively view each of the pictures. Each block of emotional (positive and negative) and neutral pictures consisted of four pictures which were presented for 3500 ms/each, with 500 ms fixation cross in between the presented pictures. Thirty-two positive, 32 negative and 32 neutral pictures were drawn from the IAPS picture set (see above) for the localizer task. The primary reason for including a localizer task was to identify regions that responded selectively for