A functional magnetic resonance imaging investigation of short-term source and item memory for negative pictures

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We investigated the hypothesis that arousal recruits attention to item information, thereby disrupting working memory processes that help bind items to context. Using functional magnetic resonance imaging, we compared brain activity when participants remembered negative or neutral picture–location conjunctions (source memory) versus pictures only. Behaviorally, negative trials showed disruption of short-term source, but not picture, memory; long-term picture recognition memory was better for negative than for neutral pictures. Activity in areas involved in working memory and feature integration (precentral gyrus and its intersect with superior temporal gyrus) was attenuated on negative compared with neutral source trials relative to picture-only trials. Visual processing areas (middle occipital and lingual gyri) showed greater activity for negative than for neutral trials, especially on picture-only trials. *NeuroReport* 17:1543–1547 © 2006 Lippincott Williams & Wilkins.

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Introduction

Current interdisciplinary interest in emotion–cognition interactions is considerable. Of particular interest to cognitive and clinical neuroscientists is the seemingly paradoxical effect that arousal, especially from negative information, can have on episodic memory: negative content (e.g. pictures, words) seems to be especially well remembered [1–4] compared with neutral information, but memory for the source (i.e. context) of the information is sometimes disrupted (e.g. location [5]; but see, e.g., [2,6]; see [7] for a review). Such a pattern maps well onto clinical reports from patients with disorders such as posttraumatic stress disorder, in which memory for the content of the traumatic event is often quite vivid whereas memory for contextual information is weak [8].

To understand this paradox, we have been investigating the impact of arousal on memory binding processes – those cognitive processes that help us establish and later remember associations between individual features of an experience – and on the brain areas involved. We take as the point of departure for this study our recent findings [5] that (a) short-term source memory (in this case, memory for picture–location conjunctions) was disrupted as the arousal value of pictures increased, and (b) relative to source memory for low arousal pictures, source memory for high arousal pictures was associated with greater activity in areas involved in visual processing [fusiform, middle temporal/occipital and lingual gyri (see [9] for a review)] and less activity in areas associated with feature integration and working memory (precentral–superior temporal intersect, superior precentral gyrus) [5,10–13]. We suggested that arousal recruits attention to the content of individual items, thereby disrupting working memory processes that facilitate binding items to their context [5]. Such attention should enhance memory for the pictures, but hurt memory for where each picture was located. The current experiment investigated this hypothesis directly by comparing source versus picture-only memory tasks within the same individuals: we examined brain activity when participants tried to remember either negative high arousing or neutral picture–location conjunctions, as in the study by Mather *et al.* [5], versus when they tried to remember only the pictures.

During scanning, participants were asked to remember on each trial, in different runs, either the locations of four complex pictures (*source*) or just the pictures (*picture*) over a brief delay. All pictures in a trial were either negative high arousal or relatively neutral low arousal. Participants were tested, with a single probe, on the to-be-remembered information. They returned about 7 weeks later for a long-term picture recognition test outside the scanner. As

expected: (a) short-term source memory was disrupted on trials with negative high arousal pictures compared with neutral pictures, but there was no disruption on picture-only trials; (b) visual processing areas (middle temporal/occipital gyri, lingual gyrus) were more active for negative than for neutral information, especially on the picture-only trials; (c) areas related to working memory (superior precentral gyrus) and feature integration (inferior precentral-superior temporal intersect) were especially disrupted on the negative source trials; (d) long-term picture recognition memory was better for negative than for neutral pictures.

Methods

Participants

Nineteen healthy, right-handed students (10 female students, $M_{age} = 20.6$ years, range = 18–27 years) with normal (or corrected to normal) vision participated; none were taking psychotropic medications. The Human Investigation Committee of the Yale Medical School approved the procedures; participants gave signed, informed consent and received a small monetary compensation.

Design and materials

The design was a 2 (emotion: negative high arousal, neutral) × 2 (memory task: source, picture only). We compiled 180 high arousal negative ($M_{arousal} = 6.15$, $M_{valence} = 2.63$, each on a scale of 1–9 with higher arousal numbers meaning greater arousal, lower valence numbers meaning more negative) and 180 low arousal neutral ($M_{arousal} = 3.67$, $M_{valence} = 6.44$) complex color pictures. Negative pictures included, for example, combat scenes, medical procedures, insects, snakes, and so on. Neutral pictures included, for example, people engaged in neutral activities, nature scenes, animals, household items, and so on. Most (266) of the pictures were from the International Affective Picture System [14]; 94 pictures were from other sources and were rated by laboratory members. The same pictures were studied in the source and picture conditions, but were randomly assigned to different four-item sets and locations in each test condition. Different items were tested in each condition; probes were counterbalanced across participants so that pictures tested in the source condition for one participant were tested in the picture condition for another.

Procedure

Outside the scanner, participants received instructions and completed eight practice trials to acquaint them with the tasks. In the scanner, participants were told before the start of each run what they were to remember (picture + location, picture only). Each trial took 22 s, with one full brain volume image (i.e. scan) collected every 2 s (TR = 2000 ms). Thus, there were 11 functional scans per trial. On each trial, participants saw four pictures from the same emotional category – negative or neutral – shown sequentially for 990 ms each, with a 10-ms interstimulus interval. Each picture appeared in a different one of six possible unmarked locations. After a 7.5-s blank delay, a cue appeared for 500 ms to remind the participant of the condition and response mapping. The test probe, shown for 2 s, followed the cue. For the source task, the probe was one of the four pictures from the trial in one of the locations used during that trial. Targets were a picture seen on that trial in its original location; lures were a picture from that trial repaired with a different location from that trial. For the picture task, the probe was a picture that either had (target) or had not (lure) been seen on that trial, presented in the middle. Probes were half targets and half lures. Participants pressed a button in their left hand to indicate 'same' (target) or their right hand to indicate 'different' (lure). To decrease variability from uncontrolled mental activity between trials, the test probe was followed by an 8-s intertrial interval during which two arrows were presented sequentially for 1400 ms each and participants pressed a button with their left (right) hand if the arrow pointed left (right).

Four *source* and four *picture* runs were pseudorandomly presented such that half of the studied pictures were presented first on source trials and repeated on picture trials and vice versa. Each run had 20 trials: two five-trial mini-blocks each of negative and neutral trials, with the mini-blocks pseudorandomly varied across runs across participants. Across runs and participants, each condition–emotion pairing appeared nearly equally often in each ordinal position within the session, and the pictures were novel on half the trials of each condition–emotion cell. Each cell of the design consisted of 40 trials.

About 7 weeks after scanning ($M = 51.4$ days, range = 32–78 days), 16 participants returned for an unexpected long-term picture recognition test. The test contained 240 pictures: all 160 of the tested pictures from the scan session, 40 of the studied but untested pictures, and 40 new pictures chosen from the same pool but not seen in the scan session matched with the old items as closely as possible for semantic content and arousal/valence. Item types were pseudorandomly intermixed and in the same order for everyone. Pictures were shown for 4500 ms with 500 ms between, and participants made two responses via button press: (a) whether they did or did not remember seeing the picture in the scanner (2500 ms), (b) their confidence from 1 (low) to 3 (high) (2000 ms).

Imaging details

Anatomical images were acquired for each participant using a 1.5-T Siemens Sonata scanner (Siemens Medical Solutions, Malvern, Pennsylvania, USA). Functional scans were acquired with a single-shot echoplanar gradient-echo pulse sequence (TR = 2000 ms, TE = 35 ms, flip angle = 80°, FOV = 24). The 26 axial slices (3.75 × 3.75 mm in plane, 3.8 mm thick) were anterior commissure–posterior commissure aligned. Each run began with 12 blank seconds to allow steady-state magnetization. One full brain volume (i.e. scan) was collected every 2 s, or 11 full brain scans for each trial (440 images per participant per cell).

Functional magnetic resonance imaging analyses

Data were motion corrected using a six-parameter automated algorithm (AIR) [15]. A 12-parameter AIR algorithm was used to co-register participants' images to a common reference brain. Data were mean-normalized across time and participants and spatially smoothed (three-dimensional, 8 mm full-width at half-maximum).

Our interest was in the activity during the encoding portion of the trial for the visual and binding areas emphasized in the study by Mather *et al.* [5]. We used the clusters of activation found in that study as a mask,

applying those regions of interest to the unthresholded per voxel signal values of the functional data in the current study. We then calculated, for each person for each region for each emotion–condition cell, the percentage signal change from the first scan in the trial during each subsequent scan within a trial (i.e. at scans 2–11) and averaged across all trials of that type. These mean percentage changes, which reflect changes across the trial in response to within trial events, were submitted to planned comparisons looking at the differences between the negative and the neutral trials in each condition separately (source, picture) for scans 3–6 which, allowing for the hemodynamic response, should capture activity associated with stimulus presentation and the early part of the delay period (encoding).

Results and discussion

Accuracy was measured using d'.

Behavioral data: short-term memory

Planned comparisons of negative versus neutral trials for the picture and source tasks separately showed that whereas negative ($M=2.70$) and neutral ($M=2.85$) pictures were remembered equally well ($P>0.20$), location source memory was significantly worse for negative ($M=1.97$) than for neutral ($M=2.39$) trials [$F(1,18)=10.15$, $M_{Se}=0.160$, $P<0.01$].

Behavioral data: long-term memory

A t-test confirmed that participants remembered significantly more negative ($M=0.71$) than neutral ($M=0.37$) [$t(15)=3.82$, $P<0.01$] pictures, with 14 of the 16 participants showing this pattern. The difference was in greater hits for negative ($M=0.42$) than for neutral ($M=0.28$) pictures, rather than in false alarms ($M=0.20$, 0.19 for negative and neutral, respectively). Although participants' confidence in their accurate decisions (hits) did not differ with emotional content ($M=2.14$, 2.06 for negative and neutral, respectively; $P>0.10$), they were more confident in their false alarms to neutral ($M=2.09$) than to negative ($M=1.76$) [$t(12)=2.85$, $P=0.01$] pictures, supporting the idea that they remembered the neutral pictures less accurately. [*N*s vary for confidence because: (a) owing to a technical problem, confidence ratings were not collected from one participant, and (b) not all participants made false alarms.]

Together, the behavioral data support the idea that negative arousing information disrupts source memory in the short term, but enhances long-term item memory.

Functional magnetic resonance imaging data

As predicted, in regions associated with visual processing, including the middle occipital and middle temporal gyri, activity was greater on negative than on neutral trials, and this difference was especially marked for the picture trials. For the area in Fig. 1b, activity during encoding was greater for negative than for neutral picture trials [$F(1,18)=3.87$, $M_{Se}=0.004$, $P=0.06$], but there was no difference for negative versus neutral source trials ($P>0.50$). For the area in Fig. 1a, negative trials showed greater activity for both memory tasks [$F(1,18)=8.92$, 23.11, $M_{Se}=0.002$, 0.001, for source and picture, respectively, $P<0.01$ in both cases], but the difference was numerically greater on the picture trials. As the same pictures appeared in the source and picture tasks, these differences are unlikely to have been caused by factors that might be correlated with arousal level of the pictures, such as complexity or number of people. Rather, this pattern is consistent with greater attention to the content of high arousal negative pictures than to the content of neutral pictures, contributing to their greater likelihood of later being remembered.

In contrast, in areas associated with working memory and feature binding, including the intersect of the inferior precentral/superior temporal gyri and left superior precentral gyrus, activity was greater on neutral than on

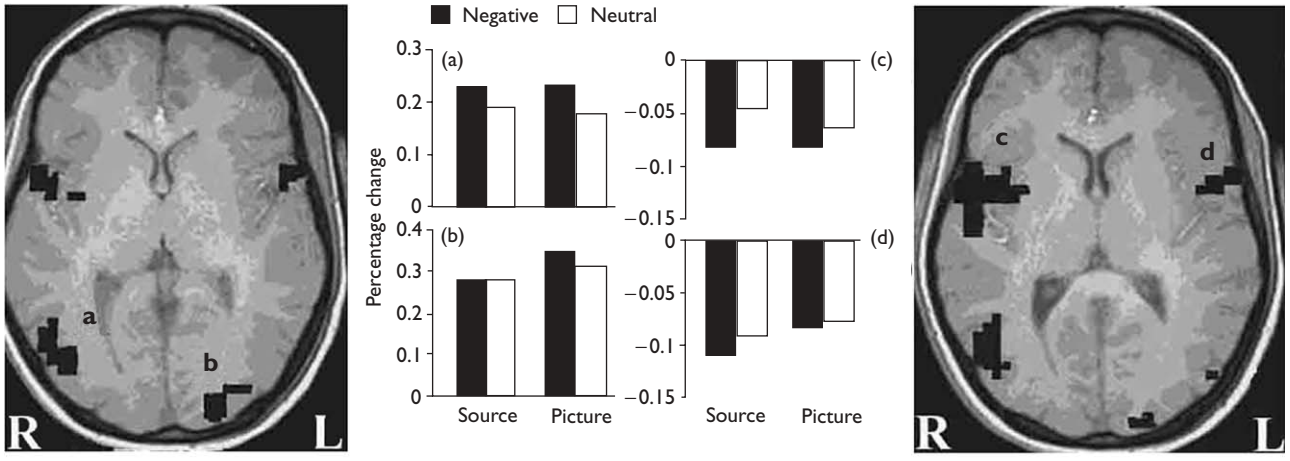

Fig. 1 Areas showing differential activity between negative and neutral trials for either the picture (a, b) or the source (c, d) task. Two representative slices chosen [$z\sim4$ (top), $z\sim9$ (bottom)]; bar graphs show the mean of the percentage change for scans 3–6 (encoding). (a) The area of the right middle temporal and occipital gyri, inferior temporal gyrus ($x=41$, $y=-76$, $z=-4$) showing more activity on negative than on neutral trials in both conditions, but the difference was numerically greater on picture trials than on source trials. (b) The area of the left calcarine sulcus, lingual gyrus, middle occipital gyrus (-28, -83, -2) in which activity did not differ for the source trials but negative trials showed greater activity than neutral trials for the picture task. (c, d) Bilateral areas of the precentral, superior temporal and inferior frontal gyri (49, -2, 10; -46, 2, 5) showing no significant difference on the picture task, but greater activity on neutral than on negative trials in the source task.

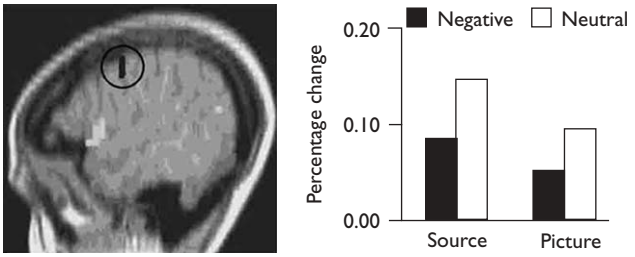

Fig. 2 The area of the left precentral gyrus/BA6 (−45, −8, 45) showing greater activity for neutral than for negative trials that was numerically greater on the source task than on the picture task.

negative trials. These differences were greater in the source than in the picture task. The intersect of the left inferior precentral gyrus and superior temporal gyrus (Fig. 1d) showed significantly greater activity on neutral than on negative source trials [$F(1,18)=9.58$, $M_{Se}=0.001$, $P<0.01$] but no difference on picture trials ($P>0.20$). The right homologue (Fig. 1c) showed a similar, but slightly attenuated pattern [source: $F(1,18)=3.83$, $M_{Se}<0.001$; $P=0.07$; picture: $P>0.30$]. Activity in these areas has been associated generally with working memory [10], and there is evidence that the superior temporal sulcus serves as a cross-modal integration area [13,16]. The precise loci of activity across studies varies as a function of the modalities of the stimuli to be integrated and the nature of the task [17,18], but studies to date have not examined the kind of complex pictorial-location integration encouraged in our task. We tentatively suggest that the activity seen here is associated with integration of complex pictorial and spatial information during encoding and that disruption of this integration occurs when negative emotional information is involved.

The left superior precentral gyrus (Fig. 2) showed more activity on neutral than on negative trials for both tasks [$F(1,18)=12.61$, 6.67, for source and picture, $M_{Se}=0.003$, $P<0.02$ in both cases], but the difference was numerically greater for the source trials. This area has been associated with memory binding in other working memory studies [5,11,12], although its precise functional role remains to be clarified. The left Brodmann area (BA) 6 is active in both verbal [19,20] and location-based working memory tasks [21], and it has been suggested that this region is part of a subvocal rehearsal circuit [20,22] and is involved in covert spatial attention [23,24]. Together, the evidence suggests that activation in this region during the current task may be associated with shifts in spatial attention during cross-modal rehearsal of the picture–location combinations. The functional relationship between the superior rehearsal area and the more inferior integration areas remains to be explored.

Interestingly, a similar working memory binding study [12] using only neutral items showed age-related disruption on picture–location conjunction trials in the medial prefrontal cortex (BA 10) and hippocampus, but not in an area of the superior precentral gyrus whose hotspot was within a few voxels (−54, −5, 35) of the current area (Fig. 2). It may be that emotion affects a different subset of processes involved in binding than does aging. Thus, one question for future studies is what factors selectively disrupt various processes of memory binding at different stages, from initial perception to long-term consolidation, and in which populations.

Conclusions

Convergent with the hypothesis raised in the study by Mather *et al*. [5], the current findings provide direct evidence that emotionally arousing negative pictures recruit more visual attention than do neutral pictures. This *mental rubbernecking* [25] comes at the expense of the kinds of reflective processing necessary for binding during working memory.

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