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The Role of Overt Attention in Emotion-Modulated Memory

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The presence of emotional stimuli results in a central/peripheral tradeoff effect in memory: memory for central details is enhanced at the cost of peripheral items. It has been assumed that emotion-modulated differences in memory are the result of differences in attention, but this has not been tested directly. The present experiment used eye movement monitoring as an index of overt attention allocation and mediation analysis to determine whether differences in attention were related to subsequent memory. Participants viewed negative and neutral scenes surrounded by three neutral objects and were then given a recognition memory test. The results revealed evidence in support of a central/peripheral tradeoff in both attention and memory. However, contrary with previous assumptions, whereas attention partially mediated emotion-enhanced memory for central pictures, it did not explain the entire relationship. Further, although centrally presented emotional stimuli led to decreased number of eye fixations toward the periphery, these differences in viewing did not contribute to emotion-impaired memory for specific details pertaining to the periphery. These findings suggest that the differential influence of negative emotion on central versus peripheral memory may result from other cognitive influences in addition to overt visual attention or on postencoding processes.

Keywords: emotion, memory, attention, eye movement monitoring

It is well-noted that presence of an emotional element may result in a central/peripheral tradeoff effect in memory: memory for central, emotional aspects of an event is enhanced, and memory for peripheral, nonemotional aspects of an event is impaired (e.g., Christianson, 1992; Adolphs, Tranel, & Buchanan, 2005; Reisberg & Heuer, 2004; Loftus, 1979; Loftus, Loftus, & Messo, 1987; Brown, 2003). It is argued that the process underlying this tradeoff effect in memory is attentional narrowing (e.g., Kensinger, Piguet, Krendl, & Corkin, 2005; Kensinger, Gutchess, & Schacter, 2007; Wessel & Merckelbach, 1997) such that when an emotionally arousing stimulus, specifically a negative stimulus, is present (Derryberry & Tucker, 1994; see also Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009), attention will "narrow" like a spotlight and be focused primarily on it (Posner, 1980; Easterbrook, 1959), resulting in better encoding and subsequent memory (e.g., Craik, Govoni, Naveh-Benjamin, & Anderson, 1996) for the central emotional object and impaired encoding and subsequent memory for the neutral objects in the periphery. In support of this, there is an abundance of literature showing that when emotionally arousing and neutral stimuli are simultaneously presented, arousing stimuli preferentially capture and sustain attention (e.g., Loftus et al., 1987; Bradley, 1994; Stormark, Nordby, & Hugdahl, 1995; Anderson & Phelps, 2001; Armony & Dolan, 2002; Calvo & Lang, 2005; Anderson, 2005; Nummenmaa, Hyönä, & Calvo, 2006; Öhman, Flykt, & Esteves, 2001; Öhman & Mineka, 2001). However, whereas there is evidence showing that highly arousing and negatively valenced emotions lead to attention narrowing and that a central/

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peripheral tradeoff effect occurs in memory, the co-occurrence of both effects does not necessarily imply that the former mediates the latter.

Only two studies have examined the relationship between emotion-modulated attention and the central/peripheral tradeoff effect in memory within the same experiment (Wessel, van der Kooy, & Merckelbach, 2000; Christianson, Loftus, Hoffmann, & Loftus, 1991). In both studies, researchers used eye movement behavior as a measure of overt attention during encoding and found evidence in support of attention narrowing, specifically, participants spent longer looking at the central details of the critical slide if it was negatively arousing than if it was neutral and less time looking at the peripheral details of the slide when it appeared in a negative context than when it appeared in a neutral context. In a subsequent test phase, both studies reported higher recall and recognition accuracy for central negative versus neutral details, but contrary to the notion that more attention results in better memory, Christianson and colleagues (1991) found that those who directed more viewing to the central aspects of the scene did not have higher recognition memory scores than those who directed less viewing. Wessel and colleagues (2000) did not directly examine the relationship between eye movement measures recorded during the encoding phase and recall memory at the test phase. Because neither study found a difference in memory for peripheral details, it is not known whether attention narrowing results in a central/peripheral tradeoff in memory per se. As such, it is possible that the relationship between attention narrowing and the central/peripheral tradeoff in memory is not a unitary phenomenon, that is, differences in attention may mediate differences in memory for peripheral details but not central details or vice versa.

To address the extent to which the central/peripheral tradeoff effect in memory is caused by attention narrowing, we performed a mediation analysis (Baron & Kenny, 1986; MacKinnon, Fairchild, & Fritz, 2007) to examine the relationship between overt attention, as measured by eye movement monitoring (EMM), and subsequent memory performance in a paradigm that elicited both emotion-enhanced memory for central negative pictures and emotion-impaired memory for peripheral items. A mediation analysis allowed us to examine the observed relationship between an independent (emotion) and dependent (measure of memory) variable via the inclusion of a third or mediator variable (measure of attention). The use of EMM can reveal differences in overt attention allocation and scanning patterns during encoding which reveals not only *what* was attended, but also how extensively it was attended.

In the present experiment, participants' eye movements were monitored while they studied a central picture that was either neutral or negatively arousing, surrounded by three neutral everyday objects in the periphery. It is important to note that the central picture and the peripheral objects did not overlap in space or meaning (see Reisberg & Heuer, 2004). After a brief delay, memory for central pictures and peripheral objects was assessed separately in the test phase in which previously viewed and novel central pictures and previously viewed, manipulated and novel peripheral objects were presented. To the extent that the emotion-modulated central/peripheral tradeoff effect in memory is related to differences in overt attention allocation, measures of attention should mediate the relationship between emotion and memory. On the other hand, if differences in attention do not mediate the relationship between emotion and memory, then this would suggest that emotion affects memory via mechanisms other than attention. This may include direct modulation as well as indirect modulation via mechanisms such as differences in postencoding influences on memory formation.

Method

Participants

Twenty-four undergraduate students (mean age = 19.17 years, 3 males; 1 left-handed) from the University of Toronto participated for course credit. All participants had normal neurological histories and had normal or corrected-to-normal vision.

Stimuli and Design

The materials used to create the experimental displays consisted of 48 pictures taken from the International Affective Picture System (IAPS), of which 24 had a negative valence and 24 were of neutral valence (Lang, Bradley, & Cuthbert, 1999) and 192 neutral objects (Hemera Photo Objects). Each display consisted of one picture in the center and three objects randomly placed in the periphery. The everyday objects were judged by the authors (LR and DM) and two independent raters to be neutral and nonarousing. All pictures chosen from the IAPS set included people. The negative pictures had a more negative valence ($t = -17.03$, $p < .001$) and were more arousing ($t = 14.02$, $p < .0001$) than the neutral pictures. The complexity of the pictures was assessed in terms of the number of bytes of the image files in JPEG format, that is, more complex images should have a larger file size (Boudo, Sarlo, & Palomba, 2002; Nummenmaa, Hyönä, & Calvo, 2006). We found that there were no differences between the negative and neutral set of pictures used, $t(46) = .63$, $p > .1$. Each display was divided equally into a 3 × 3 grid (not presented to the participants), and the central picture was always placed in the center cell with the three objects randomly placed in the periphery. The three objects in the periphery did not overlap in physical space or semantic meaning with the central element but were always distinct and not relevant to the meaning of the central scene (Burke, Heuer, & Reisberg, 1992; Reisberg & Heuer, 2004). A manipulated version was constructed for each display in which one of the three peripheral objects was replaced with a novel object. In the test blocks, the central pictures and peripheral objects were presented separately. Central pictures were either previously presented (repeated) or entirely new (novel). Peripheral objects contained the same three objects presented during the study phase (repeated), two previously studied objects, and one novel object (manipulated) or three novel objects that were not presented during the study phase (novel). Peripheral objects in the repeated and manipulated displays were presented in the same spatial location as seen during the study phase. For all displays of peripheral objects in test block, a black box was placed in the location previously occupied by the central picture so that judgments of repetition/manipulation/novelty could only be based on the peripheral objects rather than the central picture. Counterbalancing of the display occurred such that each version of the display appeared equally often in each experimental condition (repeated/novel for central pictures; repeated/manipulated/novel for peripheral objects) and paired with each emotion (negative, neutral) across participants.

Procedure

Eye movements were measured throughout the study and test phases with a SR Research Ltd. Eyelink 1000 eye-tracking desktop monocular system and sampled at a rate of 1000 Hz with a spatial resolution 0.1°. A chin rest was used to limit head movements. A 9-point calibration was performed at the start of the experiment followed by a 9-point calibration accuracy test. Calibration was repeated if the error at any point was more than 1°. Participants studied 32 randomly presented displays (16 negative, 16 neutral) once in each of two study blocks.[1] The displays were 1024 × 768 pixels in size and subtended approximately 33.4 degrees of visual angle when seated 25″ from the monitor. Consistent with previous procedures in which a central/peripheral tradeoff was observed (e.g., Kensinger et al., 2005; Kensinger et al., 2007), each display was presented for 2 s followed by a 3-s interstimulus interval. Participants were instructed to freely view the scene, and they were not told that there would be a subsequent memory test. After a 10-min delay (approximately) in which participants completed a background information form, participants' memory for the peripheral objects and central pictures was assessed separately across four test blocks. The first two test blocks involved passively viewing 16 previously studied, 16 manipulated and 16 novel peripheral object displays, and 32 previously studied and 16 novel pictures. Eye movement data from this test phase is not presented in the present paper but is discussed elsewhere (Riggs, McQuiggan, Anderson, & Ryan, 2010). In the final two test blocks, the same materials were presented again following procedures as in our previous work (e.g., Ryan, Althoff, Whitlow, & Cohen, 2000). Participants were informed that they would be seeing the last two blocks of pictures again but now they had to indicate whether a set of peripheral objects was exactly the same as during the study sessions ("repeated"), had changed in some way ("manipulated"), or had not been viewed during the study session ("novel"). In the last test block, participants had to indicate whether a central picture was the same ("repeated") or different ("novel") from what they had seen during the study blocks.

Analysis

To examine the role of attention on subsequent memory, measures derived from EMM were used to quantify the amount of overt attention allocated to the central and the peripheral objects in each display. Previous research shows that during the encoding phase, it is the number of eye fixations, rather than duration of viewing, that predicts subsequent memory performance (e.g., Loftus, 1972). In the present experiment, the number of fixations was used to characterize eye movement behavior and provide an index of the amount of viewing/overt attention directed *within* a particular region during the study phase. A fixation was defined as the absence of any *saccade* (e.g., the velocity of two successive eye movement samples exceeds 22°/s over a distance of 0.1°) or blink (e.g., pupil is missing for three or more samples) activity. Each fixation is separated by a saccade. Analysis of eye movements was performed with respect to the experimenter-drawn interest areas corresponding to the location of central picture and peripheral objects. During the test phase, evidence of memory was obtained via verbal reports of recognition. Recognition accuracy was measured as the proportion of correct responses to novel and repeated central pictures and novel, repeated, and manipulated peripheral objects. Reported hits for central pictures were corrected for false alarms. Reported hits to repeated and manipulated peripheral objects are presented uncorrected for false alarm rates, because we were interested in how processing and memory of peripheral objects are modulated by emotion, and novel peripheral objects were never paired with either emotional or neutral pictures.

To address the question of whether the central/peripheral tradeoff effect is related to the amount of overt attention at study, we performed a mediation analysis (Baron & Kenny, 1986) using a bias-corrected bootstrap method (standard Monte-Carlo algorithm) for assessment of indirect effects built into AMOS (Preacher & Hayes, 2004; MacKinnon, Lockwood, & Williams, 2004). Specifically, viewing as indexed by the number of fixations during study blocks 1 and 2 was included in the mediation analysis as a measure of overt attention. Viewing during both study blocks was included in the analysis because subsequent memory performance cannot be attributed to a single study block only. Emotion and memory for each trial were entered as binary variables with 1 representing negative pictures and 0 representing neutral pictures and with 1 representing a correct response and 0 representing an incorrect response, respectively. The degrees of freedom for the regression analysis were 24. This allowed us to determine whether the relationship between emotion and memory was (1) indirectly mediated by attention either fully or partially or (2) direct and not mediated by attention. By "direct" we mean that the path between emotion and memory remained statistically significant even after controlling for attention. A significant direct effect may be the result of the influence of emotion on memory via mechanisms other than overt attention, including direct modulation as well as other unquantified third variable factors.

[1] In designing the present experiment, we had two aims: to explore the relationship between emotion-modulated attention and memory (current paper) and to examine whether a tradeoff in memory performance can be observed and the retrieval process outlined using eye movement monitoring (Riggs et al., 2010). Previous eye movement studies of memory have reported significant differences in viewing novel versus repeated stimuli only after multiple exposures (e.g., Althoff et al., 1998; Ryan et al., 2007). Therefore, since we planned to measure memory using both eye movement monitoring and verbal reports, we presented all of the stimuli twice across two study blocks and assessed memory first indirectly by eye movement monitoring and then directly via verbal reports. Indirect assessment of memory via eye movement monitoring always occurred before the direct measure of memory via verbal reports because previous eye movement studies of memory have reported memory effects in eye movement behavior during free viewing of the stimuli when participants were not explicitly instructed to perform a memory task (e.g., Ryan et al., 2000).

Results

Study Blocks

The extent to which participants directed more viewing to the central picture (and, as a consequence, less viewing to the peripheral objects) when it was negative versus when it was neutral was considered to provide evidence for emotion-modulated attention narrowing.

Analyses of variance (ANOVA) were conducted on the number of fixations[2] directed to particular regions of interest using emotion (negative, neutral), region type (central, peripheral), and block (block 1, block 2) as within-subject factors. All possible interactions were evaluated. Differences in viewing were evident in significant main effects for region type such that participants directed more fixations to the central pictures versus peripheral objects, $F(1, 23) = 29.28$, $p < .0001$, $d = .56$. The main effect of emotion was also significant; participants sampled the entire display with more fixations when the central picture was negative compared with when it was neutral, $F(1, 23) = 6.64$, $p < .05$, $d = .22$. A significant main effect of block was also observed $F(1, 23) = 10.10$, $p < .01$, $d = .31$); there was in a decrease in the number of fixations across study blocks. A significant three-way interaction was found between emotion, region type, and block ($F(1, 23) = 31.99$, $p < .0001$, $d = .58$) (Figure 1), and follow-up *t* tests were used to explore this interaction.

Consistent with the attention-narrowing hypothesis, in the first study block, participants directed significantly more fixations to negative relative to neutral central pictures, $t(23) = 5.54$, $p < .0001$, and significantly fewer fixations to peripheral objects that were paired with negative than neutral pictures, $t(23) = -7.61$, $p < .0001$. During the second study block, there were no significant differences in the number of fixations directed to negative versus neutral central pictures, $t(23) = .89$, $p > .1$. This change of viewing across study blocks was the result of decreased fixations to negative central pictures, $t(23) = 4.03$, $p < .01$. There were no significant changes in the number of fixations to neutral central pictures across study blocks, $t(23) = .32$, $p > .1$. For peripheral objects, participants continued to direct more fixations to peripheral objects that were paired with neutral versus negative central pictures, $t(23) = -2.28$, $p < .05$.

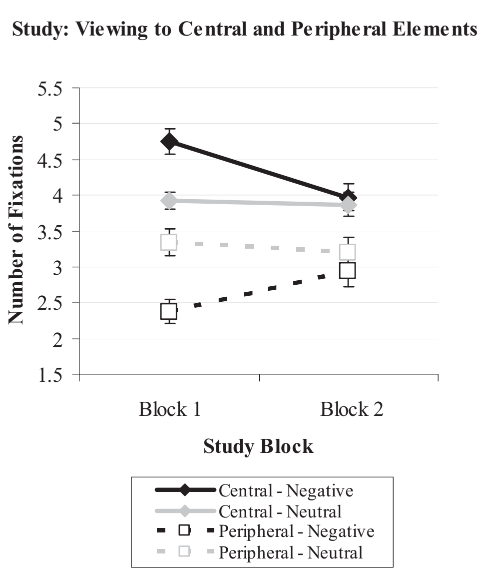

Figure 1. Participants initially directed more fixations to central scenes when they were negative compared to when they were neutral and fewer fixations to peripheral objects when they were paired with negative versus neutral central pictures. In the second study block, viewing to negative central pictures decreased, which likely resulted in a corresponding increase in viewing the associated peripheral objects.

In summary, the presence of an emotional central stimulus led to an initial tradeoff in attention, such that more overt attention was allocated to a negative versus a neutral central picture and less attention was allocated to peripheral objects when they were paired with negative versus a neutral central picture. Further, although this attention-narrowing effect was significantly attenuated in the second study block, there was still evidence of emotion-modulated tradeoff in attention allocation for peripheral objects. Below, we examine whether emotion also led to a tradeoff in memory as measured by verbal report.

Test Blocks

Verbal recognition reports. Consistent with the notion that emotion enhances memory for central details, participants were more accurate (hits minus false alarms) in identifying repeated central pictures when they were negative compared to when they were neutral, $t(23) = 2.86$, $p < .01$. Accuracy for repeated peripheral objects did not differ by emotionality, but participants were less accurate in identifying manipulated peripheral objects if they were previously paired with a negative central picture versus a neutral central picture, $t(23) = -2.19$, $p < .05$. All relevant means and standard errors are presented in Table 1.

Mediation Analysis

In the current study, emotion-modulated tradeoffs in overt attention to central and peripheral elements as measured by EMM and tradeoffs in recognition memory for central pictures and manipulated peripheral objects were observed. However, it is not known whether the tradeoffs in memory performance were a result of the tradeoffs in the allocation of attention. The number of fixations to central and peripheral elements was used as an index of overt attention in the mediation analysis. This allowed us to examine whether the amount of fixations to central pictures was predictive of subsequent memory for central pictures and whether the amount of fixations to peripheral objects was predictive of subsequent memory for peripheral objects.

In examining the total relationship between emotion and accuracy, a regression analysis revealed that negative emotion contributed significantly to higher accuracy for central pictures ($\beta = .24$, $p < .01$) and lower accuracy for manipulated peripheral objects ($\beta = -.09$, $p < .05$). Consistent with the behavioral results, emotion did not contribute significantly to accuracy for repeated

[2] The same pattern of results was obtained when we examined eye movement measures of duration of viewing and proportion of fixations, that is, the number of fixations directed to a particular region of interest relative to the total number of fixations directed to the entire visual display.

Table 1
Mean Responses and Standard Errors for Peripheral Objects and Central Pictures

	Peripheral objects					
	Neutral			Negative		
Response type	Novel	Manipulated	Repeated	Novel	Manipulated	Repeated
Novel	.43 (.05)	.17 (.03)	.15 (.03)	N/A	.23 (.04)	.19 (.04)
Manipulated	.26 (.03)	.28 (.03)	.22 (.03)	N/A	.20 (.03)	.19 (.03)
Repeated	.31 (.04)	.55 (.04)	.63 (.04)	N/A	.57 (.05)	.62 (.05)

	Central pictures					
	Neutral			Negative		
	Novel	Repeated	Repeated (corrected)[a]	Novel	Repeated	Repeated (corrected)
Novel	.64 (.07)	.26 (.04)	N/A	.54 (.08)	.08 (.02)	N/A
Repeated	.36 (.07)	.74 (.04)	.56 (.03)	.46 (.08)	.92 (.02)	.69 (.04)

[a] Accuracy for central pictures was calculated as hits minus false alarms.

peripheral objects ($\beta = .004$, $p > .1$); therefore, we did not examine this relationship further. In examining the relationship between emotion and attention, it was found that emotion was associated with enhanced sampling, that is, more fixations of central pictures ($\beta = .14$, $p < .05$) and decreased sampling of manipulated peripheral objects ($\beta = -.09$, $p < .05$).

Having established a significant relationship between emotion and memory performance, it was critical to ascertain whether this relationship was fully, partially, or not at all mediated by attention. To do this, we conducted mediation analyses separately for central pictures and manipulated peripheral objects. For central pictures, the indirect path between emotion and memory, with attention as a mediator, was significant (path a $*$ path b: $\beta = .02$, $p < .05$) (Figure 2), suggesting that attention may mediate the relationship between emotion and memory. However, it was also found that even when attention was fixed, the direct path (path c) between emotion and accuracy remained significant ($\beta = .23$, $p < .05$). In other words, attention only partially mediated emotion-enhanced recognition memory for central pictures. For manipulated peripheral objects, the indirect path was not statistically significant ($\beta = -.0004$, $p > .1$), and the direct path between emotion and accuracy for manipulated peripheral objects remained significant even when the variable of attention was fixed ($\beta = -.09$, $p < .05$).[3] Thus, the results suggest that although emotion led to decreased viewing of peripheral objects, these changes did not play a significant role in reducing one's ability to identify changes in the periphery.

In summary, emotion led to tradeoffs in attention. Participants directed more overt attention to negative versus neutral central pictures and less attention to peripheral objects paired with negative versus neutral central pictures. Emotion also led to a central/peripheral tradeoff effect in memory. Recognition was more accurate for negative versus neutral central pictures and less accurate for manipulated peripheral objects previously paired with negative versus neutral central pictures. However, the mediation analysis revealed that differences in emotion-modulated memory, especially memories of the details in the periphery, cannot fully be explained by differences in attention allocation during the encoding phase. Rather, the current analysis suggests that factors other than overt attention may mediate the relationship between emotion and the central/peripheral tradeoff effect.

Discussion

The presence of emotional stimuli has typically resulted in a central/peripheral tradeoff effect in memory. It has been suggested that these memory differences are the result of attention narrowing during encoding (e.g., Kensinger et al., 2005, 2007; Wessel & Merckelbach, 1997). However, the relationship between attention narrowing and the central/peripheral tradeoff effect in memory has not been directly examined in a study where emotion was found to modulate memory for both central and peripheral items. In the current study, it was found that consistent with previous research, emotion enhanced attention toward, and memory for, centrally placed pictures. Specifically, participants directed more attention to, and were more accurate in identifying, repeated negative versus neutral central pictures. Emotion also led to decreased attention to objects in the periphery and less accurate memory for identifying manipulations in the periphery that were both spatially and conceptually distinct from the central picture. The present work addressed whether attention narrowing was related to the central/peripheral tradeoff in memory through mediation analysis. The results here revealed that differences in overt attention during the study phase cannot fully account for subsequent memory performance. Specifically, although attention mediated some of emotion's effects on memory, it did not mediate the entire relationship.

[3] A potential concern with using the raw number of fixations as an overt measure of attention is that there may be significant between-subjects variance in the total of fixations directed. One way to control for these individual differences is to use the measure of proportion of fixations. When we performed the mediation analysis using the proportion of fixations as the measure of overt attention, the same pattern emerged as was found using number of fixations.

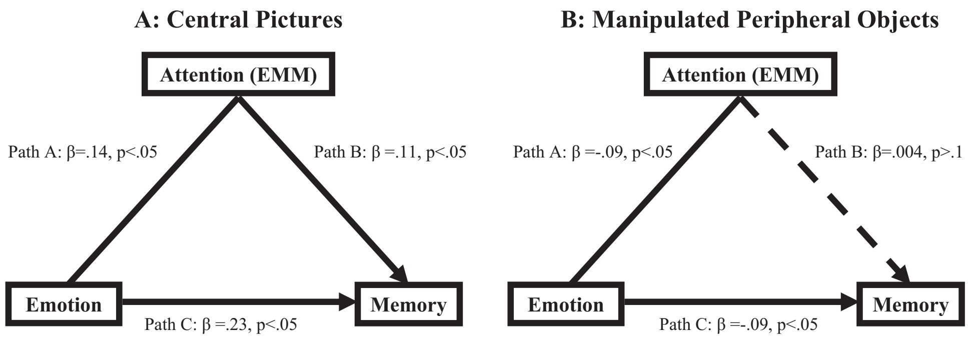

Figure 2. A mediation model with emotion, attention (number of fixations), and memory. The left hand panel (A) shows the relationship between the three variables for central pictures, and the right panel (B) shows the relationship for manipulated peripheral objects. Solid lines represent significant relationships, whereas dashed lines represent nonsignificant relationships. Attention was a significant mediating factor between emotion and memory for central pictures only. Emotion and/or other unquantified variables modulated memory for both central pictures and manipulated peripheral objects.

This suggests that cognitive mechanisms other than attention are involved in modulating the relationship between emotion and the central/peripheral tradeoff effect in memory. In the next sections, we discuss our results in light of previous findings regarding the central peripheral tradeoff in attention and memory and how the current work may inform theories regarding the influence of emotion on attention and memory.

Attention Narrowing

The preferential allocation of attention toward emotional stimuli is typically regarded as an adaptive function allowing one to prioritize the detection and processing of potentially threatening and/or important information (Whalen et al., 1998). Consistent with this notion, here, participants directed more viewing to the central picture and less viewing to the surrounding peripheral objects when the central picture was negative compared to when it was neutral. This attention-narrowing effect occurred despite the fact that participants were instructed to freely view the presented displays. This supports the hypothesis that emotional pictures engage more attention (e.g., Calvo & Lang, 2005; Nummenmaa et al., 2006) and leads to attention narrowing (Easterbrook, 1959), in particular for negatively valenced events (Schmitz, De Rosa, & Anderson, 2009). These findings are also consistent with previous studies showing that when emotional and neutral stimuli are presented simultaneously, attention is biased toward the emotional stimuli (e.g., Nummenmaa et al., 2006; Calvo & Lang, 2004; Wessel et al., 2000; Christianson et al., 1991). In the present study, this attention-narrowing effect was present during the first study block but was mitigated in the second study block. This suggests that whereas negatively arousing pictures may attract increased amounts of overt attention initially, this response may habituate upon subsequent presentations, leaving participants more time and resources for the processing of peripheral objects (Nummenmaa et al., 2006; Harris & Pashler, 2004). Further, it has also been shown that participants direct less viewing to repeated versus novel stimuli (e.g., Althoff, Cohen, McConkie, Wasserman, Maciukenas, Azen, & Romine, 1998; Althoff & Cohen, 1999; Ryan et al., 2000; Ryan, Hannula, & Cohen, 2007). Thus, the decrease in viewing to negative, but not neutral, central scenes across the study blocks may reflect the influence of more detailed and/or stable memory representations on viewing behavior. In other words, the results may suggest more efficient memory encoding of negative pictures during initial presentation. All together, a significant emotion-modulated attention-narrowing effect was observed that dissipated after the first presentation of the displays, suggesting rapid formation of stable memory representations and thus rapid habituation of emotional capture of overt attention.

Central/Peripheral Tradeoff in Memory and Attention

Consistent with the eye movement data from the study phase, recognition accuracy from the test phase showed that memory for central negative pictures was more accurate than memory for central neutral pictures, and memory for manipulated peripheral objects was less accurate for those that were previously paired with negative versus neutral pictures (e.g., Kensinger et al., 2005; Brown, 2003; Wessel & Merckelbach, 1997; Pickel, French, & Betts, 2003). However, compared to previous studies (e.g., Kensinger et al., 2005, 2007), we observed that accuracy for recognizing novel central pictures was relatively lower than expected. This is likely a result of the fact that when participants had to make an explicit judgment regarding whether the central pictures were novel or previously presented, all of the test stimuli had already been presented during the eye movement test phase. Therefore, participants had to make relative novelty judgments. Further, contrary to previous studies (e.g., Kensinger et al., 2005, 2007), no emotion-modulated effects were observed for recognition of repeated peripheral objects. One important methodological difference is that whereas previous studies have presented the stimuli once during the encoding phase (e.g., Kensinger et al., 2007; Christianson, 1992; Loftus, Loftus, & Messo, 1987), we presented the stimuli twice over two study blocks. Thus, it is possible that by repeating the stimuli, the central/peripheral tradeoff effect in memory was not as robust as it would have been had the stimuli only been presented once. Therefore, an emotion-modulated effect in the repeated peripheral objects did not manifest. There is some indication in the literature that the central/peripheral tradeoff effect in memory is sensitive to methodological parameters such as the duration of exposure to the stimuli, specificity of the information interrogated during the test phase, and the length of time between encoding and retrieval (e.g., Burke, Heuer, & Reisberg, 1992; Steblay, 1992; Christianson, 1992). However, despite having presented the stimuli twice during the study blocks, we still observed an influence of emotion on the memory for the manipulated peripheral objects. The correct identification of manipulated peripheral objects may require a more detailed memory representation than the correct identification of repeated objects. This increase in difficulty was reflected in the lower accuracy of the verbal report data. Thus, the current results suggest that emotion may predominantly impact memory for the specific details in the periphery (Adolphs, Denberg, & Tranel, 2001; Adolphs et al., 2005; Denburg, Buchanan, Tranel, & Adolphs, 2003).

Contrary to the attention-narrowing hypothesis (e.g., Easterbrook, 1959; Kensinger et al., 2005, 2007; Wessel & Merckelbach, 1997), the amount of overt attention (i.e., eye movements) directed to central pictures versus peripheral objects did not fully account for the subsequent central/peripheral tradeoff seen in memory. Specifically, through mediation analysis, it was found that even when differences in overt attention to central pictures were fixed, the relationship between emotion and recognition memory remained significant. Further, even though the presence of negative central pictures led to decreased attention directed to peripheral objects, this change in attention allocation was not significantly related to the memory impairment observed. One possibility is that because very little attention was directed toward the peripheral objects during the encoding phase, emotion-modulated differences in attention were not large enough to affect subsequent memory performance. Another possibility is that because participants viewed all stimuli twice across two study blocks, this may have attenuated the effects of emotion-modulated attention on subsequent memory. However, despite viewing the stimuli twice, participants continued to direct fewer fixations to objects paired with negative central pictures than those paired with neutral pictures.

Taken together, the current results suggest that the presence of emotion enhanced memory for central emotional information via overt attention and additional mechanisms. Further, it was also found that emotion impaired memory for neutral information in the periphery via mechanisms other than overt attention. Given that the attention-narrowing account does not fully explain the central/peripheral tradeoff observed, below, we consider some alternate mechanisms.

Mechanisms Underlying Emotion-Enhanced Memory

One factor that has often been invoked to explain emotion-modulated memory is the factor of distinctiveness. It has been shown that when an item is relatively distinct from its surroundings (e.g., unique features, location, color, etc.), memory for that item is enhanced, likely at the expense of memory for other items (Schmidt, 1991; Talmi, Schimmack, Paterson, & Moscovitch, 2007). However, previous studies that controlled for distinctiveness still found a significant effect of emotion above and beyond distinctiveness (Anderson, 2005; Anderson, Wais, & Gabrieli, 2006). In other studies, it has been shown that memory for central and peripheral details of unusual pictures did not differ and resembled that of neutral pictures (Christianson et al., 1991; Wessel et al., 2000). Here, distinctiveness is unlikely to account for the emotion-modulated differences in recognition of peripheral objects because those were counterbalanced across emotional conditions. However, because the central pictures were not counterbalanced across emotional conditions, it is possible that differences in the distinctiveness of negative versus neutral pictures contributed to not only memory for central pictures but also the peripheral objects with which they were presented.

In addition to distinctiveness, another mechanism that may underlie the emotion-modulated central/peripheral tradeoff effect is the amount of covert attention allocated, which can be decoupled from overt attention as measured by EMM (e.g., Posner, 1980; Rowe, Hirsch, & Anderson, 2007). However, although eye fixations and attention can be dissociated under explicit instructions, they are closely related in real world situations, because a covert shift of visual attention is reliably and quickly followed by an overt gaze shift to the attended spatial location (Reichle, Pollatsek, Fisher, & Rayner, 1998; Findlay & Gilchrist, 2003; Hoffman, 1998). Despite this, it is unknown whether emotion would impact the correlation between overt and covert attention, and any contributions from the covert allocation of attention cannot be ruled out as a factor underlying the emotion-modulated central/peripheral tradeoff in memory.

Another possible mechanism underlying the central/peripheral tradeoff may be the direct modulation of memory processes through emotional arousal. Hadley and MacKay (2004; Hadley & MacKay, 2006) have proposed that emotional arousal may act as a "glue" that preferentially binds features within an emotional item, as well as between the emotional item and its experimental context (e.g., information regarding when and where the experiment occurred), thereby facilitating the subsequent retrieval of the emotional item. At the same time, this binding of the emotional item interrupts the encoding of surrounding nonemotional items, making the nonemotional items more difficult to retrieve later (Most, Chun, Widders, & Zald, 2005; Miu, Heilman, Opre, & Miclea, 2005). On this view, the central/peripheral tradeoff effect occurs because participants preferentially encode elements within the central negative picture that interfere with the encoding of the surrounding peripheral objects. Although the theory by Hadley and MacKay refers specifically to rapidly presented stimuli ($<$200 ms), there is some evidence to suggest that even at longer presentation times, there are qualitative differences between the encoding of negative versus neutral stimuli (e.g., Kensinger, Garoff-Eaton, & Schacter, 2006; Takahashi, Itsukushima, & Okabe, 2006). In the present experiment, central negative pictures may have received prioritized processing, increased perceptual processing (Anderson & Phelps, 2001; Lim, Padmala, & Pessoa, 2009), deeper semantic processing, and/or poststimulus elaboration, leading to the disruption of the processing of the peripheral objects. In other words, when it comes to memory, it is not necessarily how *long* one spends viewing an item, but rather *how* one processes it (e.g., Craik, 2002). Thus, even when participants were attending to the peripheral objects, they may have still been elaborating and/or rehearsing information associated with the negative central picture. This may also explain why overt attention during the study phase was not a significant mediating factor for memory of manipulated peripheral objects.

Consistent with the idea that there are qualitative differences in encoding emotional and neutral information, research shows that special neural and hormonal processes exist to enhance emotional, but not neutral, memories. For example, results from human and nonhuman animal studies (Cahill & McGaugh, 1998) reveal amygdala activation is significantly correlated with subsequent memory performance (e.g., Packard & Cahill, 2001; Dolcos & Cabeza, 2002; Talmi et al., 2008; Kensinger & Corkin, 2003; Anderson et al., 2006). Critically, the amygdala may mediate enhanced processing of emotional information that is separate from any increases in attention (Anderson & Phelps, 2001). In addition, given the amygdala's critical role in post encoding modulation of memory consolidation (Cahill & McGaugh, 1998; McGaugh, 2000; Adolphs, Tranel, & Denburg, 2000), and in mediating the central-peripheral tradeoff (Adolphs et al., 2001; 2005), it is possible that amygdalar modulatory influences during consolidation may also play a role. Further, consistent with the notion that the central/peripheral tradeoff effect in memory cannot be fully explained by emotion-modulated differences in attention during encoding, Payne and colleagues (2008) found that after a 12-hr sleep period, the central/peripheral tradeoff effect was even more pronounced than it was when memory was tested immediately or after a 12-hr wake period, because sleep led to a preservation of central emotional details within a scene and decay of peripheral details within a negative scene and all aspects of neutral scenes. In view of this, it is possible that results from the current study would have been even more robust after a 12-hr sleep period than they were at immediate testing.

Taken together, the present results suggest that, contrary to some previous assumptions, the central/peripheral tradeoff effect in memory is not entirely a result of differences in overt attention allocation. Rather, this memory effect may be related to altered covert attention, and/or may be the result of the direct influence of emotion on memory processes through cognitive mechanisms such as depth of processing, and/or specialized neuromodulatory mechanisms such as the direct modulation of the amygdala on medial temporal regions, leading to enhanced processing of emotionally arousing items at the cost of impaired processing of surrounding peripheral objects; these accounts remain to be tested in future research. Attention and memory may be independent processes to the extent that the amount of overt attention directed to an item may not predict subsequent memory performance. This may allow emotion to enhance memory for significant stimuli even when there is limited time or attentional resources to devote to the encoding of such stimuli.

Limitations and Future Directions

In addition to examining how emotion may modulate memory via cognitive and specialized neuromodulatory mechanisms, it may also be important to examine the relationship between emotion, attention, and memory under more "real-life" circumstances. The stimuli used in the present experiment delineated between central and peripheral details both spatially and conceptually. However, this may be less ecologically valid than previous studies that have examined central and peripheral details within one cohesive scene. Although it is possible that the central/peripheral tradeoff effect in attention and memory reported in the current study was more exaggerated than in previous studies given that the peripheral details were clearly irrelevant for the understanding of the central details, this is unlikely because we did not find evidence of emotion-impaired memory for repeated peripheral objects as reported in previous work (e.g., Kensinger et al., 2005, 2007). Thus, although the findings here suggest that differences in overt attention during the encoding phase do not fully explain emotion-impaired memory for specific details in the periphery that are spatially distinct and conceptually unrelated to the central details, future studies could explore whether this is also true for central and peripheral details within a cohesive and more ecologically valid paradigm.

In the present study, IAPS pictures were used to elicit negative emotion. However, rather than depicting the range of negative emotions (e.g., anger, fear, disgust), the negative pictures from IAPS are mostly associated with fear and disgust. Studies show that not only may different negative emotions result in different degrees of memory impairment for peripheral details (Talarico et al., 2009), but there are different viewing patterns and perhaps different cognitive processes engaged when viewing faces depicting anger, fear, and disgust (e.g., Susskind, Lee, Cusi, Feiman, Grabski, & Anderson, 2008; Aviezer et al., 2008; Lerner, Gonzales, Small, & Fischhoff, 2003). In a similar vein, there may be differences in viewing patterns to stimuli that elicit different emotions (e.g., fear, disgust, anger) in the viewer. For example, although disgust is associated with sensory rejection, fear is associated with enhanced sensory acquisition (Susskind et al., 2008). Thus, fear may result in a stronger central/peripheral tradeoff effect in attention and/or memory than disgust. Thus, it would be important for future studies to explore how these discrete negative emotions may differentially affect attention, memory, and the relationship between attention and memory.

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