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Emotion Processing Effects on Interference Resolution in Working Memory

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The interaction between emotion and working memory maintenance, load, and performance has been investigated with mixed results. The effect of emotion on specific executive processes such as interference resolution, however, remains relatively unexplored. In this series of studies, we examine how emotion affects interference resolution processes within working memory by modifying the Recency-probes paradigm (Monsel, 1978) to include emotional and neutral stimuli. Reaction time differences were compared between interference and non-interference trials for neutral and emotional words (Studies 1 & 3) and pictures (Study 2). Our results indicate that trials using emotional stimuli show a relative decrease in interference compared with trials using neutral stimuli, suggesting facilitation of interference resolution in the former. Furthermore, both valence and arousal seem to interact to produce this facilitation effect. These findings suggest that emotion facilitates response selection amid interference in working memory.

Keywords: emotion, working memory, interference resolution

Working memory is broadly defined as the cognitive system where internal representations are formed from newly perceived and retrieved information during the planning and execution of a task (Dudai, 2002). Recent investigations of working memory focus on executive processes—a collection of operations that act on the contents of working memory to facilitate adaptive behavior (D'Esposito, Postle, Jonides, & Smith, 1999; Richardson et al., 1996). Executive processes manipulate information in storage to focus attention on task-relevant details and inhibit task-irrelevant details, thus enabling the coordination of information according to task demands (Baddeley, 1986; Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998). It is within working memory—specifically during task planning and execution—that working memory representations can conflict and result in interference. One form of interference, proactive interference (PI), occurs when previously yet no longer relevant material interferes with the processing of currently relevant material (D'Esposito et al., 1999; Dudai, 2002; Jonides & Nee, 2006; Jonides et al., 1998). Interference resolution resolves conflict between competing task relevant and irrelevant working memory representations. One such instance of this conflict is the occurrence of PI to protect the contents of working memory (Jonides & Nee, 2006). Understanding interference resolution is important because interference significantly affects the amount of information that can be retrieved from long-term memory for use by working memory (Jonides & Nee, 2006). Researchers have even claimed that working memory as a system may have evolved to cope with interference (Engle, 2005). To further understand the complexities of how information is used by working memory for task completion, the current study examines the effect emotion has on interference resolution in working memory.

To investigate interference resolution, we used a PI Recency-probes paradigm. The Recency-probes task, based on research by Monsell (1978), measures interference resolution by placing source recognition and familiarity into conflict within working memory. This conflict induces interference on select trials that must be resolved before participants can respond to complete the trial. When reaction times and error rates between interference and non interference trials are compared, there are significantly longer reaction times and higher error rates on interference trials compared with noninterference trials (D'Esposito et al., 1999; Jonides et al., 1998). Since this PI effect was isolated, interference resolution in the Recency-probes paradigm has been subsequently examined across different age groups (Jonides, Marshuetz, Smith, Reuter-Lorenz, Koeppe, & Hartley, 2000), stimulus domains (verbal: Jonides et al., 1998; D'Esposito et al., 1999; object: Badre & Wagner, 2005), and methodologies (positron emission tomography [PET]: Jonides et al., 1998; functional magnetic resonance imaging [fMRI]: D'Esposito et al., 1999; Lesion: Thompson-Schill et al., 2002). However, to date no studies have examined how emotion affects interference resolution processes in working memory.

Much of the previous emotion and working memory research has found that while emotional state, or mood, influences working memory performance (Gray, 2001; Gray, Braver, & Raichle, 2002; Ikeda, Iwanaga, & Seiwa, 1996; Spies, Hesse, & Hummitzsch, 1996; Vieillard & Bourgeant, 2005), the use of emotional stimuli has no consistent effects on working memory (Kensinger & Cor-

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kin, 2003). For example, Kensinger and Corkin (2003) examined how the emotional content of stimuli influenced working memory performance across four tasks (the term *emotion* will be used here to refer to stimuli that have emotional content). They found emotion had no consistent impact on working memory performance, except for one task-specific impairment: participants responded more slowly to fearful faces than to neutral faces in a nonverbal working memory task (Kensinger & Corkin, 2003). The focus of this is study, however, was on whether emotion affected working memory maintenance and load properties, not on how emotion might affect the executive processing components of working memory.

To our knowledge, no studies to date have examined how emotion interacts with specific executive processes such as interference resolution *within* working memory. Examining how emotion affects the cognitive processes manipulated by interference resolution tasks, such as the Recency-probes paradigm, may provide some insight. Based on the structure of the Recency-probes paradigm, which manipulates source recognition and familiarity, emotion could influence interference resolution in this task in three possible ways: In the first possibility, the high saliency of emotional stimuli could increase the familiarity signal. If emotion increases familiarity, it should then increase the amount of interference created. In the second possibility, the additional contextual cues provided by emotional stimuli could enhance the source signal in the task. If emotion enhances the source signal, interference would then decrease, indicating that emotion facilitates interference resolution in working memory. In the third possibility, emotion could have no affect on familiarity or source recognition in the task—either because there is no effect, or because the competing impact of emotion on familiarity and source memory cancel each other, resulting in no behavioral difference.

Current working memory and emotion studies, though inconsistent in their findings, predict that if interference resolution is influenced by emotion in the same manner that maintenance and load processes in working memory are, then emotion will either impair interference resolution or have no effect on it (Kensinger & Corkin, 2003). Attention and emotion studies, however, show that emotion consistently interacts with attention, and these interactions may better inform us about how emotion affects interference resolution. Current attention literature indicates that emotion will sometimes impair attention and other times aid attention (Anderson, 2005; Anderson & Phelps, 2001; Bargh et al., 1996; Compton et al., 2003; Kasch, Rottenberg, Arnow, & Gotlib, 2002; Keil & Ihssen, 2004; Phelps, Ling, & Carrasco, 2006; Whalen, Bush, McNally, Wilhelm, McInerney, Jenike, & Rauch, 1998; Whalen, Bush, Shin, & Rauch, 2006). Specifically, emotion impairs attention task performance when participants are asked to focus on nonemotional stimuli or stimulus domains to complete the task. Emotional Stroop studies, for example, suggest that it takes participants longer to name ink colors or count the number of words presented on the computer screen when the words are emotional than when they are neutral (Compton et al., 2003; Whalen et al., 1998, 2006; Williams, Mathews, & Macleod, 1996). This research predicts that when a task requires focusing on nonemotional stimulus domains, emotion will produce a decrement in performance. In contrast, when task requirements *do not* involve the focusing of attention on nonemotional stimulus domains to perform the task, attention studies find that emotion may facilitate attention (Anderson & Phelps, 2001; Keil & Ihssen, 2004). For example, research using the attentional blink paradigm found that positive and negative arousing emotional words were associated with higher identification accuracy than were neutral words (Anderson & Phelps, 2001; Keil & Ihssen, 2004). Based on these findings, Keil and Ihssen concluded that affectively arousing information is selected preferentially from a temporal stream, and facilitates such processes as working memory consolidation. The two distinct emotion and attention interactions thus demonstrate that the way in which emotion influences interference resolution may depend on whether task requirements involve focusing attention on emotional versus nonemotional stimulus domains.

Research exploring the impact of emotion on source memory may also provide some insights into its impact on interference resolution (Davidson, McFarland, & Glisky, 2006; Doerksen & Shimamura, 2001; Hadley & MacKay, 2006). For example, source memory accuracy for the font color of emotional words, or for the cognitive operations performed during encoding, is higher for emotional words than for neutral words (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; Kensinger, Piguet, Krendl, & Corkin, 2005). Other studies have failed to replicate these findings, however, suggesting that any enhancement may be task-specific (Mather, 2007). These findings suggest that the presence of emotional stimuli in a task may alter specific memory processes, which, in turn, may enhance source recognition in working memory and facilitate interference resolution.

Taken together, research studies investigating the influence of emotion on attention and source memory (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; Kensinger et al., 2005) suggest that the enhanced contextual detail provided by emotional content will aid interference resolution when task requirements involve focusing attention on emotional stimulus domains, and impair interference resolution when task requirements involve focusing attention on nonemotional stimulus domains.

To clarify the effect of emotion on interference resolution processes in working memory, we modified the Recency-probes task (D'Esposito et al., 1999; Jonides et al., 1998; Jonides & Nee, 2006) to include emotional stimuli. To examine how emotion interacts with interference resolution in working memory, we conducted three studies. In the first study, neutral and emotional words were used as stimuli. In the second study, neutral and emotional pictures were used as stimuli to assess the generality of any observed findings across stimulus types. Finally, in the third study, the valence and arousal levels of the emotional stimuli (Russell & Barrett, 1999) were systematically varied to examine their interaction with interference resolution processes in working memory. Furthermore, to clarify the influence of focusing attention on emotional versus nonemotional stimulus domains, the Recency-probes paradigm was specifically modified to include two emotional conditions, in addition to the neutral condition. The two emotional conditions included: (1) an Emotion Probe condition, where emotional content is the focus of the trial, and (2) an Emotional Distractor condition, where emotional content, though present, was not the focus of the trial. Reaction times to trials in each condition were compared to assess the effect of emotion on interference resolution in working memory.

Experiment 1: Emotional Words and Inhibition in Working Memory

Method

Participants. Undergraduate students aged 18 years or older participated in exchange for either payment or research credit toward an introductory psychology course. A total of 44 participants were included in the final analysis (19 men, 25 women).

Stimuli. A battery of 170 arousing and neutral words (70 arousing, 100 neutral) was developed from a stimulus set used previously (LaBar & Phelps, 1998; Lang, Bradley & Cuthbert, 1999). Each set of words was selected based on arousal ratings provided by subjects in a pilot study. One set consisted of taboo-arousing words (e.g., mutilation), and the other set consisted of neutral words (e.g., chair). Words with the highest arousal ratings in the pilot study were chosen for use in the current study. The words were rated on a scale of 1 to 9 for both arousal (1 = *low arousal*, 9 = *high arousal*) and valence (1 = *negative*, 5 = *neutral*, 9 = *positive*). Emotional and neutral words were matched for word length and frequency. See Table 1 for arousal and valence means, ranges, and *SD*s.

Procedures. Participants were tested individually and given both oral and written instructions about the experimental procedures. The design was a within-subject Recency-probes paradigm modified from Jonides et al. (1998) and D'Esposito et al. (1999). Each trial was composed of a target set of three words displayed for 950 ms, followed by a delay of 3000 ms, followed by the presentation of a single probe word for 1500 ms. Participants were instructed to decide as quickly as possible whether or not the probe word matched a word in the current target set. They were instructed to indicate "Yes" by pressing a "1" on the keyboard, or "No" by pressing a "2" on the keyboard. Participants were instructed to respond as quickly and accurately as possible. There were a total of 256 trials separated into 16 blocks of 16 trials, as well as an additional 16 practice trials that were not scored. Trials within a block were separated by an intertribal interval of 5000 ms.

Trials were separated into four types: (1) *Recent No-response* trials, in which the probe did not match any items from the target set in the present trial, but did match an item from the target sets in the preceding two trials; (2) *Nonrecent No-response* trials, in which the probe matched neither items from the present target set, nor from the preceding two sets; (3) *Recent Yes-response* trials, in which the probe matched items from both the present target set and each of the preceding two sets; and (4) *Nonrecent Yes-response* trials, in which the probe matched an item from the present target set, but not from either of the preceding two sets.

To test our hypothesis of facilitated interference resolution for emotional stimuli, trials were grouped into two conditions: an Emotion condition and a Neutral condition. Each condition consisted of 8 practice trials, followed by 8 blocks of 16 trials. The order of presentation was counterbalanced. The Neutral condition consisted of neutral words, while the Emotion condition included both neutral and emotional words, strategically placed to determine the effects of emotional stimuli on inhibitory processing. The Emotion condition consisted of two subconditions: the Emotion Probe condition and the Emotion Distractor condition, each defined on the basis of whether the probe is emotional or neutral. In the Emotion Probe condition, the probe words were emotional, while in the Emotion Distractor condition, the probe words were neutral and emotional words were presented as target set members (see Figure 1 for trial examples). Emotion Probe and Emotion Distractor trials were pseudorandomly intermixed in the Emotion condition. These two subconditions were created because the interaction between emotion and interference resolution may vary depending on whether the emotional stimulus serves as the probe, (i.e., the focus of the trial) or whether it serves as a target set distractor in a neutral probe word trial.

Emotional words were present in every target set of the emotion conditions; target sets had a minimum of one emotional word and a maximum of three emotional words, with most trials having two. This proportion of neutral to emotional stimuli in the target set was intended to ensure that distinctiveness did not drive any behavioral effects. The target sets were also chosen so that the words in each set were not semantically related or easily organized into a sentence that could aid memory. Trials were counterbalanced within a block so that "No" and "Yes" responses were equally likely to precede/proceed each other. In addition, between-trial repetitions of target items were equally likely to precede "No" and "Yes"

Table 1
Stimuli Statistics for Experiments 1, 2, and 3

	Arousal		Valence	
	M (*SD*)	Range	*M* (*SD*)	Range
Experiment 1				
Neutral	2.0 (0.61)	1.15–3.6	5.23 (0.51)	3.9–6.6
Emotional	6.0 (0.83)**	4.25–8.0	2.9 (1.2)**	1.25–7.5
Experiment 2				
Neutral	3.6 (0.72)	2.4–4.0	5.04 (1.29)	2.55–7.37
Emotional	6.3 (0.64)**	5.0–7.4	2.39 (0.69)**	1.31–3.99
Experiment 3				
Neutral	4.1 (0.52)	2.5–4.7	5.2 (0.67)	2.9–7.4
Positive high arousal	6.94 (0.78)**	5.0–8.5	7.81 (0.63)**	5.6–8.9
Positive low arousal	4.9 (0.95)**	1.7–6.3	7.25 (1.2)**	4.25–8.8
Negative high arousal	6.34 (0.61)**	5.2–8.3	2.07 (0.61)**	1.1–4.3
Negative low arousal	4.53 (0.5)**	3.4 to 6.1	2.7 (0.7)**	1.4–4.6

Note. Comparison with corresponding Neutral stimulus group.
** Significance at the 0.01 level.

Target Set			Delay	Probe	ITI	Trial Type
Neutral Condition						
cabin	paper	candle	+	candle	+	Nonrecent Yes-response Neutral
flow	blanket	Cabin	+	table	+	Nonrecent No-response Neutral
wind	flow	radiate	+	cabin	+	Recent No-response Neutral
wood	plate	Flow	+	flow	+	Recent Yes-response Neutral
Emotion Conditions						
whore	follow	Rape	+	rape	+	Nonrecent Yes-response Emotion Probe
many	whore	Along	+	kindle	+	Nonrecent No-response Emotion Distractor
sex	quiet	Hate	+	whore	+	Recent No-response Emotion Probe
jacket	house	Sex	+	jacket	+	Nonrecent Yes-response Emotion Distractor
pillow	sex	Chair	+	sex	+	Recent Yes-response Emotion Probe
beard	chair	Fuck	+	terror	+	Nonrecent No-response Emotion Probe
penis	couch	Beard	+	chair	+	Recent No-response Emotion Distractor
kill	beard	Hell	+	beard	+	Recent Yes-response Emotion Distractor

Figure 1. Sample neutral and arousing words and trial types from both the Neutral and Emotion conditions (Emotion Probe and Emotion Distractor) used in Experiment 1's modification of the Recency-probes proactive interference paradigm.

responses, as well as Recent and Nonrecent trials, within each block. All words were presented approximately the same number of times.

Data analysis. Reaction times for each of the four trial types (*Recent No-response*, *Nonrecent No-response*, *Recent Yes-response,* and *Nonrecent Yes-response*) in all the three conditions (Neutral, Emotion Probe, and Emotion Distractor) were grouped, and a mean response time was calculated for each trial type in each condition for each subject. Reaction time means for all four trials types in the Neutral, Emotion Probe and Emotion Distractor conditions were compared in a $3 \times 2 \times 2$ analysis of variance (ANOVA) comparing Condition (Neutral, Emotion Probe, and Emotion Distractor), Recency (Recent and Nonrecent), and Response (No or Yes). To isolate the effects of Condition, Response or Recency on any main effects and interactions, follow-up 3×2 and one-way ANOVAs and paired t tests were conducted.

Incorrect and outlier trials were excluded from the reaction time analysis. Outlier trials were identified as trials with reaction times greater than 2.5 *SD*s from the mean. Percent accuracy for each subject for each trial type was also calculated. Due to the small number of errors made by each subject, the percent accuracy was transformed using the arc sin transformation. To detect overarching patterns of how accuracy differed by Condition, Response, and Recency, accuracy levels were selectively combined across these domains to isolate the individual effects of each.

Results

The results for Experiment 1 are presented in two sections. The first examines how emotion interacts with interference resolution and working memory response times overall. Reaction time to Nonrecent and Recent No-response trials in each condition are presented in Figure 2. The second section examines how emotion affects accuracy for interference and non interference trials within working memory.

Reaction time analysis. The $3 \times 2 \times 2$ ANOVA revealed a significant main effect for Recency, $F(1, 43) = 83.498$, $p < .001$; two significant two-way interactions: Condition and Response, $F(2, 86) = 4.441$, $p < .015$ and Recency and Response, $F(1, 43) = 93.135$, $p < .001$; and a significant three-way interaction for Condition, Recency and Response, $F(2, 86) = 5.402$, $p < .01$. Follow-up No and Yes-response Condition by Recency ANOVAs and corresponding t tests determined that the main effect of Recency and the significant interaction between Recency and Response was due to significant reaction time differences between Recent and Nonrecent No-response trials, regardless of condition (Neutral ($t(43) = 12.31$, $p < .001$), Emotion Probe ($t(43) = 6.345$, $p < .001$), Emotion Distractor ($t(43) = 9.930$, $p < .001$)). This finding is consistent with previous PI research. In addition, No and Yes response reaction times differed significantly across condition; Nonrecent Yes-reaction times were consistently longer than No-response reaction times (see Table 2). To determine how emotion affected interference, Recent and Nonrecent No-response trials were compared across condition. Results indicate that Recent but *not* Nonrecent No-response reaction times differed across condition ($F(2, 86) = 3.95$ $p < .05$). Follow-up t tests comparing Recent No-response Neutral, Emotion Probe and Emotion Distractor trial types indicate that reaction times for Recent No-response Emotion Probe trials were significantly shorter than for Neutral and Emotion Distractor trials (see Table 2). This reaction time pattern contributes to the two-way Response by Condition interaction and the three-way Condition by Recency by Re-

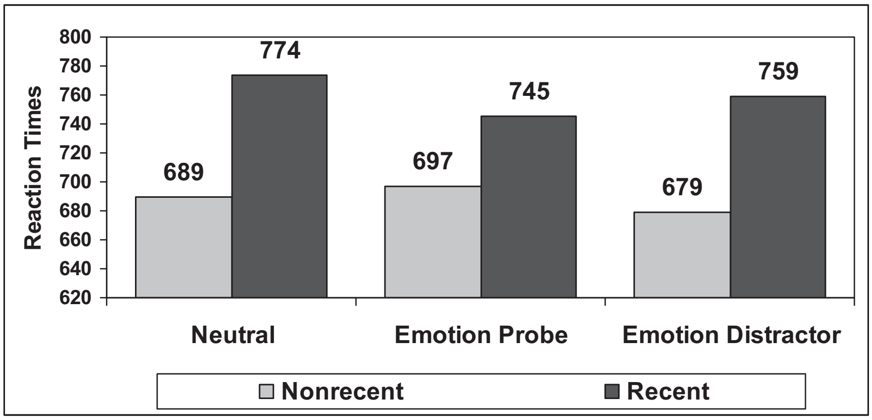

Figure 2. Nonrecent and Recent No-response times from each condition. The difference between Nonrecent and Recent No-response times is significantly less in the Emotion Probe condition compared with the Neutral and Emotion Distractor conditions.

sponse interaction found in the primary ANOVA. In addition, because interference occurs only in Recent No-response trials, these findings indicate that emotion reduces the level of interference present in working memory.

Accuracy analysis. Accuracy scores were combined across Trial type, Response, Condition, and Recency to isolate the individual effects of each domain (accuracy means are available in Table 2). Pairwise *t* tests indicated that "Yes" responses contained significantly more errors than "No" responses ($t(43) = 6.416$, $p < .001$). In addition, Recent trials contained significantly more errors than Nonrecent trials ($t(43) = 4.986$, $p < .001$). Interesting to note, there were also significant error rate differences between the three emotion conditions, $F(2, 86) = 23.262$, $p < .001$. While there were no cumulative error rate differences between Emotion Probe and Emotion Distractor trials, Neutral trials contained significantly more errors than both Emotion Probe ($t(43) = 6.132$, $p < .001$) and Emotion Distractor ($t(43) = 4.584$, $p < .001$) trials.

Discussion

This study, designed to explore the interactions between emotion and interference resolution in working memory, had three principle findings. First, we found significantly longer reaction times for interference than for noninterference trials, replicating the PI effect (Badre & Wagner, 2005; D'Esposito et al., 1999; Jonides et al., 1998; Jonides & Nee, 2006; Thompson-Schill et al., 2004). Second, interference was reduced in conflict trials with emotional stimuli. Recent No-response Emotion Probe trials had significantly shorter reaction times than Recent No-response Neutral and Emotion Distractor trials. Although the mechanism behind this finding remains unclear, emotional information seemed to facilitate response selection amid interference in working memory.

Third, the data also showed consistent baseline working memory differences. Nonrecent Yes-response trials produced consistently longer response times than Nonrecent No-response trials, yet there was no indication that emotion was contributing to these reaction time differences. Although reaction time differences between "No" and "Yes" responses on trials is not unusual, it is unique that "Yes" responses take longer than "No" responses. Previous research conducted by Sternberg (1969) found that "No" responses typically take longer than "Yes" responses. Our data demonstrated the opposite finding. Perhaps in this instance, the presence of repeated words throughout the experiment had a detrimental effect on "Yes" response times. As words were repeated, participants took longer to correctly respond "Yes" to a trial because they first needed to confidently determine the source of the word in the face of possible previous repetitions. Interesting

Table 2
Experiment 1: Nonrecent and Recent No- & Yes-Response Trial Reaction Times for Each Condition

Trial types	*M* (*SD*)	Accuracy (%)		*M* (*SD*)	Accuracy (%)
Neutral: Yes-responses			Neutral: No-responses		
Nonrecent	728 (146)	92.8	Nonrecent	689 (140)	99
Recent	713.5 (132)	86	Recent	774 (158)	95
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	720 (144)	96	Nonrecent	697 (130)	97
Recent	714 (131)	96.8	Recent	745 (134)*	97.7
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	736 (122)	94.7	Nonrecent	679 (136)	98
Recent	729 (134)	97	Recent	759 (129)	96

Note. Arousal and Valence comparisons with corresponding Neutral condition trial type ($df = 43$).
** Significance at the 0.01 level.
* Significance at the 0.05 level, *t* = trend at the 0.1 level.

to note, the accuracy data confirms this hypothesis: higher error rates were found for "Yes" than for "No" response trials. Effectively, in a paradigm with frequent stimulus repetitions, participants may take longer to reach the level of confidence required to make a correct "Yes" response than they would in a paradigm with no repetition.

As expected, the accuracy data also replicated previous PI findings: more errors were found on Recent trials compared with Nonrecent trials. In addition, there were fewer errors overall in the Emotion Condition trials than there were in the Neutral trials, suggesting emotion may increase accuracy. Furthermore, fewer errors for trials with emotional versus neutral words make it unlikely that any facilitation of interference resolution for emotion is due to a speed/accuracy-tradeoff.

Experiment 2: Emotional Pictures and Inhibition in Working Memory

Method

The second experiment used the same variant of the Recency-probes paradigm in Experiment 1, except the stimuli were changed from words to pictures. The results of Experiment 1 indicated that verbal emotional information facilitates interference resolution in working memory. This experiment was conducted to determine if the facilitation of interference resolution in working memory for emotion extends to other types of emotional stimuli.

Participants. As in Experiment 1, undergraduate students aged 18 years or older participated in exchange for either money or research credit toward an introductory psychology course. A total of 45 participants were included in the final analysis (18 men, 27 women).

Stimuli. Sixty-four arousing and neutral pictures (44 emotional, 20 neutral) selected from the International Affective Picture System (IAPS) developed by Lang et al. (1999) were used as stimuli. An additional 28 neutral pictures were included in the stimuli set to control for scene complexity and the presence of people across the emotional and neutral sets. The arousing pictures in this experiment were all negatively valenced because positively valenced pictures of the same arousal level were of a sexual nature, which had the potential to introduce confounds such as gender-specific differences (Bradley, Codispoti, Sabatinelli, & Lang, 2001). The negatively arousing pictures included bodily mutilations, dead animals, car or plane accidents, guns, and animals that are commonly the source of phobias (snakes and insects). The neutral pictures included objects, animals, individuals and groups of individuals engaging in everyday activities (e.g., man next to a mailbox, group walking in street, or view of storefront activities) designed to match the complexity of the emotional scenes.

Each set of pictures was selected based on normative valence and arousal ratings from the IAPS technical manual, or on arousal ratings provided by pilot New York University subjects utilizing the same IAPS scale. The pictures were rated on a scale of 1 to 8 (1 = *low arousal*, 8 = *high arousal*). All arousal and valence means, ranges, and *SD*s are presented in Table 1. In addition to arousal, the visual complexity and content of the scene was considered when selecting pictures. For example, a picture of a dead animal in the arousing set would be balanced in the neutral set by a neutral picture of an animal in a similarly complex scene.

Procedures. The design of Experiment 2 was similar to that in Experiment 1, except in Experiment 2 the length of stimulus presentation was changed to reflect the increase in stimulus complexity. The three target pictures were displayed for 1300 ms instead of 1050 ms. The trial delay was 3,000 ms, the probe display was 1500 ms, and the intertribal interval was 5000 ms. Participants completed both neutral and emotion conditions that were counterbalanced across participants. Participants were presented with the same set of written and oral instructions, with one exception: they were warned about the negative and graphic nature of some of the emotional pictures. Participants were told that if they found any of the stimuli too upsetting, they could stop the experiment and leave without losing remuneration or credit.

Data analysis. The analyses done for Experiment 2 were the same as those done for Experiment 1 with one addition: due to Baseline Nonrecent No-response reaction time differences across the three conditions, an analysis on reaction time difference scores between all Nonrecent No-response and Recent No-response trials was also conducted. In this paradigm, interference resolution is operationalized as the difference between Nonrecent and Recent No-response trials, since Recent trials have interference and Nonrecent trials do not. Therefore, Nonrecent No-response trials were subtracted from Recent No-response trials to calculate reaction time difference scores for each condition for each subject. The resulting reaction time difference scores were compared across condition to isolate changes in interference level.

Results

The results for Experiment 2 are presented in two sections. The first examines how emotion interacts with interference resolution and working memory response times overall. Reaction time to Nonrecent and Recent No-response trials in each condition are presented in Figure 3. The second examines how emotion affects accuracy for interference and noninterference trials within working memory.

Reaction time analysis. As in Experiment 1, Reaction time means were compared in a $3 \times 2 \times 2$ ANOVA. The ANOVA revealed a significant main effect for Recency, $F(1, 44) = 66.855$, $p < .001$; three significant two-way interactions: Condition and Recency, $F(2, 88) = 5.636$, $p < .005$; Condition and Response, $F(2, 88) = 4.082$, $p < .05$; and Recency and Response, $F(1, 44) = 49.521$, $p < .001$; and a significant three-way Condition, Recency, and Response interaction, $F(2, 88) = 3.415$, $p < .05$. As was the case in Experiment 1, the main effect of Recency, and the interaction between Recency and Response was due to longer Recent than Nonrecent No-response trials (but not Yes-Response trials) across Condition (Neutral ($t(44) = 12.33$, $p < .001$), Emotion Probe ($t(44) = 3.742$, $p < .001$), Emotion Distractor ($t(44) = 6.965$, $p < .001$)). This significance pattern replicates the PI effect. Also similar to Experiment 1, Nonrecent Yes-responses had consistently longer reaction times than Nonrecent No-responses. Specifically, Yes-responses (See Table 3) were significantly longer than No-responses in the Neutral and Emotion Distractor conditions, but not in the Emotion Probe condition. These reaction time differences, along with the PI effect, contributed to the Condition by Response and Recency by Response interactions found in the primary ANOVA.

Results from Experiment 2 yielded one finding that diverged from Experiment 1. In Experiment 1, there were no baseline Nonrecent No-response differences across condition. However, in Experiment 2, there were significant baseline Nonrecent No-

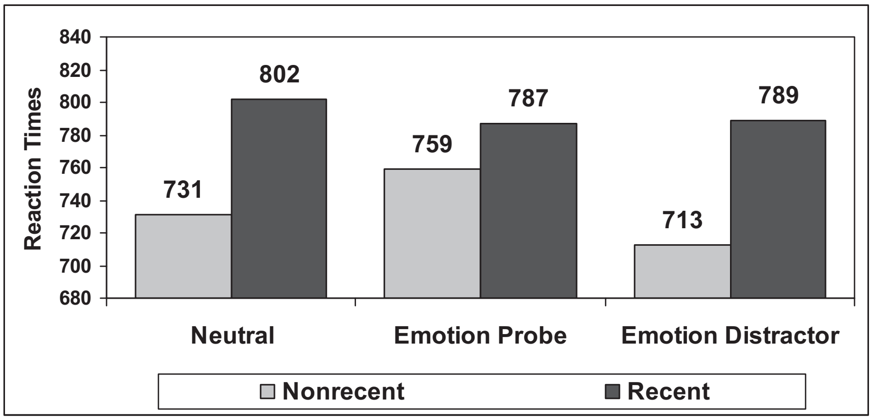

Figure 3. Nonrecent and Recent No-response times from each condition. Nonrecent No-response times are significantly greater in the Emotion Probe condition, reflecting a baseline reaction time difference between emotional and neutral pictures. Nevertheless, the difference between Nonrecent and Recent No-response times is significantly less in the Emotion Probe condition compared to the Neutral and Emotion Distractor conditions.

response differences across condition, $F(2, 88) = 6.196$, $p < .005$; see Figure 3. The source of this finding is longer Nonrecent No-response Emotion Probe trial reaction times than those in the Neutral and Emotion Distractor trials (see Table 3). The longer Emotion Probe trial reaction times were likely due to an avoidance effect associated with responding to highly arousing negative stimuli that slowed response time (Buodo, Sarlo, & Palomba, 2002; Hare, Tottenham, Davidson, Glover, & Casey, 2005; Kensinger & Corkin, 2003; Niedenthal & Kitayama, 1994; Purcell, Stewart, & Skov, 1998).

Because of this baseline difference, to measure any interactions between interference resolution and emotion, a reaction time difference score between Nonrecent No-response trials and Recent No-response trials was calculated. This difference score was then compared across conditions via a one-way ANOVA that revealed significant difference score changes across Condition, $F(2, 88) = 10.967$, $p < .001$. Follow up paired t tests conducted on the difference scores determined that Recent and Nonrecent No-response reaction time differences were significantly *smaller* in the Emotion Probe condition than reaction time differences in both the Neutral ($t(44) = 4.877$, $p < .001$) and Emotion Distractor ($t(44) = 3.695$, $p < .001$) conditions. Because the difference scores represent the magnitude of interference present in each condition, smaller difference scores in the Emotion Probe condition than in the Neutral and Emotion Distractor Conditions replicate the findings in Experiment 1, and confirm that emotion facilitates interference resolution within working memory.

Accuracy analysis. Accuracy levels were combined across Response, Condition, and Recency to isolate the individual effects of each. In contrast to Experiment 1, *only* Yes-responses (88%) had significantly more errors than No-responses (94%) ($t(44) = 4.676$, $p < .001$). All other comparisons—differences dependent upon Recency and Condition—were not significant. These results replicated findings from Experiment 1, indicating that stimulus repetition interacts with response criteria. In addition, the absence of accuracy differences between emotion and neutral trials makes it unlikely that a speed/accuracy trade-off contributed to the lower reaction time difference scores in the Emotion Probe condition.

Discussion

The goal of this study was to extend the emotional facilitation of interference resolution effect found in Experiment 1 to an additional stimulus domain. Using emotional pictures as stimuli, we

Table 3
Experiment 2: Nonrecent and Recent No- & Yes-Response Trial Reaction Times for Each Condition

Trial types	*M* (*SD*)	Accuracy (%)		*M* (*SD*)	Accuracy (%)
Neutral: Yes-responses			Neutral: No-responses		
Nonrecent	767 (140)	88.7	Nonrecent	731 (140)	96
Recent	774 (156)	89.7	Recent	802 (141)	93
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	776 (143)	91	Nonrecent	759 (135)*	94
Recent	771 (138)	92	Recent	787 (125)	88.5
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	784 (141)	82.5	Nonrecent	713 (136)	98.6
Recent	777 (155)	86	Recent	789 (138)	96

Note. Arousal and Valence comparisons with corresponding Neutral condition trial type ($df = 44$).
** Significance at the 0.01 level.
* Significance at the 0.05 level, t = trend at the 0.1 level.

were able to replicate the PI effect, the reduction of interference for emotional stimuli, and the consistent reaction time and accuracy differences between "No" and "Yes" trial responses seen in Experiment 1. The principle difference from Experiment 1 was the presence of working memory baseline differences between the three conditions. Reaction times to Nonrecent No-response Emotion Probe trials were slower than Nonrecent No-response trials in the Neutral and Distractor conditions. Previous studies have found shorter reaction times to negative valence arousing stimuli (Buodo et al., 2002; Hare et al., 2005; Kensinger & Corkin, 2003; Niedenthal & Kitayama, 1994; Purcell et al., 1998). However, the design of the present study did not have the scope to address whether these effects are specific to working memory processes, or whether the reaction time differences to No-responses for emotional pictures are simply a byproduct of the pictures' emotional content, rather than reflecting working memory processes. Interesting to note, Recent No-response trials in the three conditions should have followed the same reaction time pattern seen in the Nonrecent No-response trials, yet they did not. Instead, reaction times for Recent No-response trials in the Emotion Probe condition were shorter than those for Recent No-response trials in both the Neutral and Emotion Distractor conditions—this is opposite to the pattern seen in Nonrecent No-response trials. Given these baseline differences, reaction time difference scores between Nonrecent and Recent No-response trials served as a better indicator of interference resolution changes across all three conditions. Comparing the reaction time difference scores across conditions revealed significantly less interference in the Emotion Probe condition, supporting the facilitation of interference resolution conclusion found in Experiment 1. Together, the findings from Experiments 1 and 2 indicate that emotion, regardless of how it is elicited (i.e., by words or pictures), facilitates interference resolution within working memory.

Experiment 3: The Influence of Arousal and Valence on Inhibition in Working Memory

Method

The results of Experiments 1 and 2 indicate that task-relevant emotional stimuli facilitate inhibitory processing in working memory. Emotion, however, is not a unitary construct and reactions to emotional stimuli have a number of components (Scherer & Ellgring, 2007). One common technique that has been used to examine the components of emotion, and that may contribute to its influence on cognition, is to characterize emotional stimuli along the dimensions of valence and arousal (Barrett, 2004; Posner, Russell, & Peterson, 2005). This third experiment was conducted to determine whether the facilitation of interference resolution is due to the valence or arousal component of emotional stimuli, or both. To this end, we attempt to investigate the effect of valence (positive or negative) or arousal (intensity of response) on interference resolution independently. This was done by manipulating the level of arousal for both positive and negative emotional words

Participants. Undergraduate students aged 18 years or older participated in exchange for payment. Of the 52 participants, 16 were men and 36 were women.

Stimuli and design. A total of 384 emotional words from the ANEW battery developed by Bradley and Lang (1999) served as emotional stimuli. For neutral stimuli, 500 neutral words were chosen from the ANEW list and from a neutral word battery developed by Francis and Kucera (1982). Each set of words was selected based on valence and arousal ratings provided by Bradley and Lang (1999) or Francis and Kucera (1982). The words were grouped as follows. The 384 emotional words were separated into 4 groups of 96 words each. One group comprised negative valence, high arousal words (e.g., mutilation, terror, murder), a second group comprised negative valence, low arousal words (e.g., stink, deformed, blister), a third group comprised positive valence, high arousal words (e.g., desire, treasure, erotic), and the fourth group comprised positive valence, low arousal words (e.g., soft, protected, dignified). The 500 neutral words formed one large group of words (e.g., chair). The words were rated on a scale of 1 to 9 to measure both arousal (1 = *low*, 9 = *high*) and valence (1 = *low: negative*, 9 = *high: positive*). Emotional and neutral words were matched for word length and frequency. See Table 1 for arousal and valence means, ranges, and *SD*s for each valence and arousal condition. Trials were counterbalanced within a block so that "No" and "Yes" responses were equally likely to precede/proceed each other. In addition, between-trial repetitions of target items were equally likely to precede "No" and "Yes" responses, and Recent and Nonrecent trials within each block. All words used within each group were presented approximately the same number of times.

Procedures. The basic procedure was the same as that in Experiment 1, except there were more trials overall due to the addition of emotional stimulus sets that varied by both valence and arousal. The experiment consisted of 556 trials separated into 18 blocks of 30 trials each, as well as an additional 16 practice trials that were not scored in data analysis. The 540 scored experimental trials consisted of 60 trials in each neutral and valence/arousal group of each condition (9 neutral and valence arousal groups, with 4 trial types in each group). Participants completed the neutral and emotion conditions over a two-day period to avoid any fatigue effects. The experimental trials were divided into two presentation orders. Within each presentation order, participants completed neutral trial blocks as well as emotional trail blocks of each of the valence-arousal stimulus sets. Presentation order was counterbalanced over two consecutive days. On each day, participants completed 8 practice trials followed by 270 experimental trials separated into 9 blocks of 30 trials.

Data analysis. As with Experiments 1 and 2, reaction times were grouped into a mean response time for each trial type in each condition, and incorrect and outlier trials were excluded. Analyses were divided into four groups based on valence and arousal level: Positive High Arousal, Positive Low Arousal, Negative High Arousal, and Negative Low Arousal. Trial types in each valence-arousal group were further subdivided into the Emotion Probe and Emotion Distractor conditions yielding a total of 8 emotion subgroups. A mean response time for each subject was calculated for each trial type in the Neutral condition and in each of the 8 emotion subgroups (namely, Positive High Arousal Emotion Probe, Positive High Arousal Emotion Distractor, Positive Low Arousal Emotion Probe, Positive Low Arousal Emotion Distractor, Negative High Arousal Emotion Probe, Negative High Arousal Emotion Distractor, Negative Low Arousal Emotion Probe, Negative Low Arousal Emotion Distractor). A reaction time analysis was conducted between the neutral and all 8 emotion trial groups to measure interference resolution within working memory. Reaction times to neutral trials served as the baseline for emotional trials. A $3 \times 2 \times 2$ ANOVA comparing Condition (Neutral, Emotion Probe, and Emotion Distractor), Recency (Recent and Nonrecent), and Response (No or Yes) was conducted for each valence arousal group. Multiple 3 × 2 and one-way ANOVAs and pairwise *t* tests were conducted as follow-up.

To recap, each subject performed trials of four trial types (Nonrecent No-response, Nonrecent Yes-response, Recent No-response and Recent Yes-response trials). All the trials were further divided into 9 groups—one Neutral and 8 emotion subgroups—which were compared to measure the valence and arousal components of emotional stimuli on interference resolution in working memory.

Results

The results for Experiment 3 are presented in six sections. The first four sections examine the reaction time data across the neutral and emotional conditions for each of the four valence/arousal levels (Positive High Arousal, Positive Low Arousal, Negative High Arousal, and Negative Low Arousal). Reaction times for Nonrecent and Recent No-response trials in each condition are presented in Figure 4. The fifth section compares neutral and emotion condition reaction times across the four valence/arousal levels. The sixth and final section examines accuracy.

Positive high arousal: Reaction time analysis. The 3 × 2 × 2 ANOVA revealed two significant main effects: Recency, $F(1, 51) = 59.659$, $p < .001$ and Response, $F(1, 51) = 23.178$, $p < .001$; one significant two-way interaction: Recency and Response, $F(1, 51) = 59.892$, $p < .001$; and a trend toward a significant three-way interaction for Condition, Recency and Response, $F(2, 102) = 2.648$, $p < .075$. As in Experiments 1 and 2, the main effect of Recency, and the Recency by Response interaction was due to significantly longer reaction times for Recent No-response trials than for Nonrecent No-response trials, regardless of Condition ((Neutral ($t(51) = 9.647$, $p < .001$), Emotion Probe ($t(51) = 5.677$, $p < .001$), Emotion Distractor ($t(51) = 5.752$, $p < .001$)). In addition, the primary 3 × 2 × 2 ANOVA showed a significant main effect for Response. Follow-up Condition by Response ANOVAs and corresponding paired *t* tests conducted on Yes versus No trials indicated that, unlike previous experiments, there were no significant differences between *Nonrecent* No and Yes-response trials across conditions. There was, however, a main effect of Response, $F(1, 51) = 14.9$ $p < .001$, as well as a significant interaction between Condition and Response, $F(2, 102) = 19.35$ $p < .001$, for *Recent* trials. Follow-up *t* tests indicate that response times for Recent No-response trials were consistently longer than for Recent Yes-response trials across condition; Neutral, $t(51) = 6.852$, $p < .001$; Emotion Probe, $t(51) = 5.37$, $p < .001$; Emotion Distractor, $t(51) = 5.\ 2$, $p < .001$; with Neutral condition trials showing the largest difference. This reaction time pattern is also due to the PI effect, since interference is present in Recent No-response, but not in Recent Yes-response trails.

To determine whether positive high arousal stimuli facilitate interference resolution, a one way Recent No-response ANOVA was conducted across conditions. Interesting to note, unlike Experiments 1 and 2, the Recency No-response ANOVA did not show a main effect of condition. However, *t* tests conducted between Recent No-response, Neutral, and Emotion Probe trials showed that reaction times for Recent No-response Emotion Probe trials were significantly shorter than for Neutral trials ($t(51) = 2.13$, $p < .05$). This finding likely contributes to the Condition by Recency by Response interaction trend, thus replicating the interference reduction found in the Recent No-response Emotion Probe trials in Experiments 1 and 2.

Positive low arousal: Reaction time analysis. The 3 × 2 × 2 ANOVA revealed two significant main effects: Recency, $F(1, 51) = 48.790$, $p < .001$ and Response, $F(1, 51) = 10.947$, $p < .01$; one significant two-way interaction: Recency and Response, $F(1, 51) = 42.695$, $p < .001$; and a significant three-way interaction for

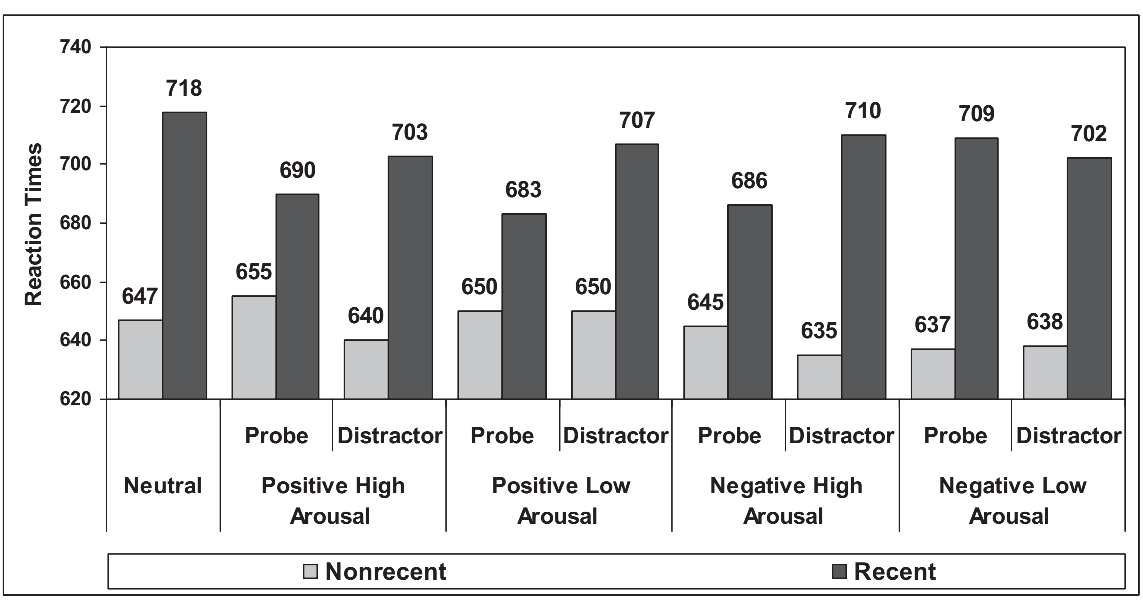

Figure 4. Nonrecent and Recent No-response times from each condition. The difference between Nonrecent and Recent No-response times is significantly less in the Emotion Probe conditions compared to the Neutral and Emotion Distractor conditions in the Positive High Arousal, Positive Low Arousal, and Negative High Arousal conditions, yet not in the Negative Low Arousal condition.

Condition, Recency and Response, $F(2, 102) = 5.719$, $p < .01$. Consistent with the findings of Experiments 1 and 2, additional ANOVAs and *t* tests determined that the source of the Recency and Response main effects and Recency by Response interaction were as follows: (1) Significantly longer reaction times for Recent No-response trials than for Nonrecent No-response trials, regardless of condition; Neutral, $t(51) = 9.647$, $p < .001$, Emotion Probe, $t(51) = 3.12$, $p < .01$; Emotion Distractor, $t(51) = 7.12$, $p < .001$, This was due to the PI effect, (2) Significantly longer reaction times for Recent No-response trials than for Recent Yes-response trials across condition; Neutral, $t(51) = 6.852$, $p < .001$; Emotion Probe, $t(51) = 5.62$, $p < .001$; Emotion Distractor, $t(51) = 2.01$, $p < .05$. This was again due to the PI effect.

To examine the effect of positive low arousal stimuli on interference resolution, a Recency No-response one-way ANOVA was conducted across conditions. Results indicate that the Recent No-response trial reaction times change significantly across conditions, $F(2, 102) = 4.623$, $p < .05$. Follow-up *t* tests indicate that as in Experiments 1, 2, and the Positive High Arousal condition, reaction times for the Recent No-response Emotion Probe trials were significantly shorter than for the Recent No-response Neutral ($t(51) = 2.56$, $p < .01$) and Emotion Distractor ($t(51) = 2.07$, $p < .05$) trials. This reaction time pattern reflects a decrease of interference for positive low arousal information.

Negative high arousal: Reaction time analysis. The $3 \times 2 \times 2$ ANOVA revealed a significant main effect of Recency, $F(1, 51) = 44.8$, $p < .001$ and three significant two-way interactions: Condition and Recency, $F(2, 102) = 4.261$, $p < .05$, Condition and Response, $F(2, 102) = 10.408$, $p < .001$, and Recency and Response, $F(1, 51) = 110.224$, $p < .001$. Follow-up ANOVAs and *t* tests indicate that the main effect of Recency and the Recency by Response interaction is due to longer Recent than Nonrecent No-response trial reaction times, a replication of the PI effect. In addition, the Condition by Response interaction is due to variable Yes-response reaction times across conditions, $F(2, 102) = 9.4$, $p < .001$. Paired *t* tests conducted to further examine these effects indicate that reaction times for Nonrecent Yes-response Neutral trial were shorter than for Emotion Probe ($t(51) = 3.33$, $p < .01$) and Emotion Distractor ($t(51) = 3.25$, $p < .01$) trials. Reaction times for Recent Yes-response Neutral trials versus Emotion Probe (trend, $t(51) = 1.84$, $p < .1$) and Emotion Distractor trials ($t(51) = 3.5$, $p < .001$) showed a similar pattern. As was the case in Experiments 1 and 2, this reaction time pattern may be due to a slowing of reaction time in response to negative high arousal stimuli. Also similar to Experiments 1, 2, and the Positive Arousal groups, Recent No-response reaction times differed significantly across condition, $F(2, 102) = 4.103$, $p < .05$: reaction times for Recent No-response Emotion Probe trials were significantly shorter than for Neutral ($t(51) = 2.31$, $p < .05$) and Emotion Distractor ($t(51) = 2.77$, $p < .01$) trials, reflecting a facilitation of interference resolution for negative high arousal stimuli.

Negative low arousal: Reaction time analysis. The $3 \times 2 \times 2$ ANOVA revealed significant main effects for Recency, $F(1, 51) = 81.274$, $p < .001$, and Response, $F(1, 51) = 25.760$, $p < .001$, and a two-way interaction for Recency and Response, $F(1, 51) = 68.654$, $p < .001$. Similar to previous valence-arousal groups and Experiments 1 and 2, the Recency main effect is due to significantly longer reaction times for Recent No-response trials than for Nonrecent No-response trials in each condition: Neutral ($t(51) = 9.647$, $p < .001$), Emotion Probe ($t(51) = 7.852$, $p < .001$) and Emotion Distractor ($t(51) = 7.575$, $p < .001$), thus replicating the proactive PI effect. In addition, a Condition by Response ANOVA conducted on *Recent* trials showed a main effect of Response ($F(1, 51) = 74.13$ $p < .001$) indicating that No and Yes reaction times were significantly different. Follow-up *t* tests indicate that response times for Recent No-response trials were longer than for Yes-response trials across conditions; Neutral, $t(51) = 6.852$, $p < .001$; Emotion Probe, $t(51) = 7.28$, $p < .001$; Emotion Distractor, $t(51) = 5.48$, $p < .001$. This accounts for the Response main effect and Recency by Response interaction found in the primary ANOVA.

Interesting to note, unlike Positive High and Low Arousal, and Negative High Arousal conditions, negative low arousal content does not appear to influence interference resolution in working memory. Recent No-response Emotion Probe trials in the Negative Low Arousal condition, while lower, were not significantly different than Recent No-response Neutral and Emotion Distractor trials (see Table 4). This finding indicates that negative low arousal information does not facilitate interference resolution, and therefore only select valence levels interact with interference resolution processes in working memory.

Comparing across valence/arousal levels: Reaction time analysis. To compare across the four valence-arousal groups within the Emotion Probe and Emotion Distractor conditions, four 4×2 ANOVAs of valence arousal group and emotion condition were conducted. To determine the source of any significant valence-arousal level main effects, subsequent one-way ANOVAs and paired *t* tests were conducted across all 4 valence and arousal conditions for Nonrecent and Recent Yes-response Emotion Probe and Distractor trials.

The first ANOVA compared Nonrecent No-response trials from each Emotion Probe and Emotion Distractor condition across the four valence-arousal groups. There were no significant main effects or interactions due to valence-arousal condition. The second ANOVA compared Nonrecent Yes-response trials across each valence-arousal group. The ANOVA revealed a significant main effect of valence-arousal level, $F(3, 153) = 11.096$, $p < .001$. Follow-up paired *t* tests indicate that the source of the valence-arousal effect was that Emotion Probe and Emotion Distractor trials had significantly longer reaction times for Negative High Arousal trials than for Positive High Arousal ($t(51) = 4.307$, $p < .001$; $t(51) = 3.265$, $p < .01$), Positive Low Arousal ($t(51) = 3.5$, $p < .001$; $t(51) = 2.785$, $p < .01$), and Negative Low Arousal ($t(51) = 3.368$, $p < .001$; $t(51) = 3.808$, $p < .01$) trials. The third ANOVA compared Recent No-responses across condition and valence-arousal level. The ANOVA revealed a main effect of condition, $F(1, 51) = 5.681$, $p < .05$ and a trend toward a condition by valence-arousal interaction, $F(3, 153) = 2.434$, $p < .07$. These findings were due to shorter reaction times (less interference) in the Emotion Probe condition than in the Emotion Distractor condition for Positive High Arousal, Positive Low Arousal, and Negative High Arousal Stimuli, but not for Negative Low Arousal stimuli. The fourth ANOVA, comparing Recent Yes-responses across valence-arousal levels revealed a significant main effect of valence-arousal level, $F(3, 153) = 7.636$, $p < .001$ for Emotion Distractor trials, but not for Emotion Probe trials. Follow-up *t* tests indicate that similar to Nonrecent Yes-response trials across valence-arousal level, reaction times for the Negative High Arousal Emotion Distractor condition were significantly longer than for the Positive High Arousal ($t(51) = 3.198$, $p < .01$)

Table 4
Experiment 3: Nonrecent amd Recent No- and Yes-Response Trial Reaction Times for Each Condition

Trial types	*M* (*SD*)	Accuracy (%)	Trial types	*M* (*SD*)	Accuracy (%)
Neutral condition					
Neutral: Yes-responses			Neutral: No-responses		
Nonrecent	656 (120)	93.6	Nonrecent	647 (102)	98.5
Recent	645 (117)	94.7	Recent	718 (114)	90
Positive High Arousal condition					
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	637 (134)^{t}	92	Nonrecent	655 (106)	98.6
Recent	642 (120)	96	Recent	690 (107)*	95
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	649 (111)	92	Nonrecent	640 (95)	98
Recent	649 (116)	95	Recent	703 (125)	95
Positive Low Arousal condition					
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	653 (116)	75	Nonrecent	650 (95)	98
Recent	660 (111)	93.6	Recent	683 (113)*	96
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	666 (128)	79	Nonrecent	650 (92)	99
Recent	656 (110)	95	Recent	707 (108)	95.5
Negative High Arousal condition					
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	688 (134)**	85	Nonrecent	645 (101)	97.5
Recent	669 (119)^{t}	89.6	Recent	686 (120)*	94.8
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	680 (123)*	93	Nonrecent	635 (114)	91.7
Recent	680 (117)**	88	Recent	710 (114)	89
Negative Low Arousal condition					
Emotion Probe: Yes-responses			Emotion Probe: No-responses		
Nonrecent	647 (110)	77.8	Nonrecent	637 (107)	96.8
Recent	649 (117)	89	Recent	709 (117)	81
Emotion Distractor: Yes-responses			Emotion Distractor: No-responses		
Nonrecent	630 (98)*	94.7	Nonrecent	638 (95)	97
Recent	641 (96)	94	Recent	702 (114)^{t}	93

Note. Arousal and Valence comparisons with corresponding Neutral condition trial type ($df = 51$).
** Significance at the 0.01 level.
* Significance at the 0.05 level, $t(51)$ = trend at the 0.1 level.

and Negative Low Arousal ($t(51) = 5.768$, $p < .001$) conditions, but not for the Positive Low Arousal condition.

These reaction time patterns across conditions indicate that the primary reaction time differences across the four valence-arousal groups are as follows: (1) less interference for all High Arousal stimuli, regardless of valence, and for Low Arousal stimuli of positive valence only, (2) consistently longer reaction times to Yes-response trials in the Negative High Arousal condition.

Accuracy. Accuracy levels were combined across Response, Recency, and Condition to isolate the individual effects of each. In addition, accuracy levels were combined across valence-arousal group to determine any valence-arousal condition differences. Similar to Experiments 1 and 2, when examining accuracy levels for Response, "Yes" responses overall (90%) had significantly lower accuracy than "No" responses overall (95%) ($t(51) = 6.822$, $p < .001$). Unlike Experiment 1, when analyzing accuracy levels for Recency, there was no significant difference between Nonrecent and Recent accuracy levels. Furthermore, when accuracy was measured across condition, there were significantly more Emotion Probe condition errors than Emotion Distractor ($t(51) = 7.959$, $p < .001$) and Neutral ($t(51) = 8.110$, $p < .001$) condition errors. To determine whether the low Emotion Probe accuracy level was reflected in Recent No-response Emotion Probe trials across the neutral and valence-arousal levels, a series of paired *t* tests was conducted. Results indicate that the decrease in Emotion Probe accuracy level was driven by low *Nonrecent Yes-response* Emotion Probe trial accuracy levels, not *Recent No-response* Emotion Probe trial accuracy levels (see Table 4). This accuracy pattern indicates that the reduction in Recent No-response Emotion Probe reaction time in the aforementioned valence-arousal groups was not likely due to a speed/accuracy-trade-off. When accuracy rates were compared across the four valence arousal groups, Positive, High Arousal (95%) and Neutral (94%) conditions respectively, had the highest accuracy; significantly higher than for Positive Low Arousal ($t(51) = 9.54$, $p < .001$; $t(51) = 5.677$, $p < .001$), Negative High Arousal ($t(51) = 9.01$, $p < .001$; $t(51) = 7.091$, $p < .001$), and Negative Low Arousal ($t(51) = 10.803$, $p < .001$; $t(51) = 7.073$, $p < .001$) conditions. These differences, however, were also driven by low accuracy for Nonrecent Yes-response trials in the later valence arousal conditions.

Discussion

The goal of Experiment 3 was to investigate the components of emotion, specifically valence or arousal, which contribute to the emotional facilitation of interference resolution. Results show that Positive and Negative, High Arousal Emotion Probe words facilitate interference in working memory. This pattern indicates that arousal, regardless of valence, consistently influences interference resolution. Arousal is thus one important factor affecting the facilitation of interference resolution for emotional information. In addition, Positive Low Arousal, yet *not* Negative Low Arousal stimuli significantly facilitate interference resolution in working memory. This facilitation pattern demonstrates that positive valence, regardless of arousal level, facilitates interference resolution. Interference resolution is therefore not only sensitive to arousal and valence, but also to particular arousal and valence levels. Experiment 3 also replicated the PI effect across valence-arousal groups, as well as the Yes versus No-response reaction time differences for Negative High Arousal trials found in Experiments 1 and 2. The latter replication confirms that the longer reaction times to Negative High Arousal trials than to the other valence-arousal levels is likely due to an avoidance of highly arousing negative stimuli.

General Discussion

This series of experiments was conducted with the goal of determining how emotion affects interference resolution within working memory. Based on the current emotion, memory and attention literature, emotion could either facilitate or impair interference resolution processes. We found that emotion aids interference resolution. Recent No-response reaction times were reduced for Emotion Probe trials in Experiments 1, 2 and 3 compared with Neutral and Emotion Distractor trials. The question that remains is *how* does emotion facilitate response selection amid interference in working memory? Based on the paradigm design, we will venture a possible explanation. The Recency-probes paradigm manipulates two well-studied memory processes: familiarity and source recognition. To review, the source recognition signal of "No" in Recent No-response trials is put into conflict with the familiarity signal of "Yes". A correct response to a Recent No-response trial thus requires interference resolution processes. Consequently, a decrease in the level of interference requires an increase in source signal strength, or a decrease in familiarity signal strength. Therefore, there are two hypotheses regarding the basis of the emotional facilitation of interference resolution finding. The first is that there may be special mechanisms for resolving interference with emotional stimuli that reduces the strength of the incorrect familiarity response. The second is that an enhanced encoding of emotional source memory (Doerksen & Shimamura, 2001; Tabert et al., 2001) may have increased the strength of the correct source response, decreasing interference and facilitating interference resolution for emotional information in working memory. Either one of these hypotheses alone may account for the decreased level of inhibition required, or both may act in conjunction to reduce interference for emotional information.

Unfortunately, based on the present data we cannot specify whether the observed effects are due to changes in familiarity, source recognition, or both. However, an examination of the possible neural mechanisms underlying interference resolution in working memory may provide some insight into our findings. Recent studies have isolated interference resolution within working memory to the inferior prefrontal cortex, specifically the left inferior frontal gyrus (IFG; D'Esposito et al., 1999; Jonides et al., 1998; Thompson-Schill et al., 2002). In addition, research by Nelson et al. (2003) has established that the IFG in particular resolves interference when properties of an internal representation are in conflict. According to Thompson-Schill, D'Esposito, Aguirre, and Farrah (1997) and Kan and Thompson-Shill (2004), the primary role of the IFG is to select from among multiple representations the one(s) that best serve(s) the task at hand. Recently Kan and Thompson-Shill (2004) framed this selection mechanism using the Desimone and Duncan (1995) Biased-Competition model. Applying this Biased-Competition model to the Recency-probes task and knowledge of emotional processing provides a possible explanation of the facilitation of interference resolution for emotional information.

According to the Biased-Competition model, selection is mediated by an attentional template that consists of properties relevant to the goal of some task (Jonides & Nee, 2006). In the case of this Recency-probes task, the template might be the context of items in the target set and probe. This might include the valence-arousal level for the current block of trials, the probe and target set items and their contextual associations, and any temporal context present in the trial. Essentially each item in the trial has a contextual tag linked to it and the trial template comprises these contextual tags. When a probe item is presented it is compared to the template of the target set. The greater the similarity between the probe's contextual tag and that of the target set, the greater the bias to classify the probe as a member of the target set. This, in turn, inhibits a classification of the probe as nontarget.

When stimuli are seen multiple times, however, the trial template must be adjusted to include previous trials as well. Therefore, the probe is compared to the current and previous target sets, a process which may account for the present data and provide a pathway for emotional stimuli to reduce interference. When the probe is emotional, additional PFC regions, such as the orbitalfrontal cortex (OFC), may become engaged and change the probe's contextual tag, adding emotional context, such as arousal, temporal context, and stronger representations of source. This additional emotional contextual information would aid responding to the trial. In regard to our paradigm, the additional source signal and item associations would be available for interference resolution processes in the IFG to use when conflict is present, therefore aiding response selection amid interference for emotional but not neutral stimuli. Research with OFC and IFG lesion patients performing this paradigm is needed to confirm this hypothesis.

With this explanation in place, a few additional questions arise. First, why does facilitation occur for Recent No-response Emotion Probe trials, but not for Recent Yes-response Emotion Probe trials? Additional emotional source signals should facilitate recent yes-response trials as well, but according to our data, Recent Yes-response trial reaction times do not follow the same pattern. Our primary explanation for this effect is that additional contextual information is received from connecting neural regions such as the OFC only in times of need (i.e., when there is conflict within working memory). One purpose of the OFC is to gate the influence of emotional information to ensure that emotions only influence decisions in appropriate situations (Kringelbach & Rolls, 2004; Rolls, 1996, 2004; Rule, Shimamura, & Knight, 1999). The lack of conflict in Recent Yes-Response trials may be why additional emotional context provided by the OFC was not used—it was not needed.

A second question based on the data and our interpretation of the biased-competition model is: Why were reaction times for Nonrecent Yes-response trials consistently longer than for Nonrecent No-response trials? It is possible that the constant stimulus repetitions throughout the experiment may change response criteria for a "Yes" response, causing the observed increase in response time. Because words are repeated, participants may take longer to correctly respond "Yes" to a trial, since they must first confidently determine the source of the word in the face of possible previous repetitions. These additional probe and target set comparisons would lengthen response times. The accuracy data confirms this hypothesis: there are more errors in the Nonrecent Yes-response trials than in any of the other trial types from all three experiments. This indicates that in Nonrecent Yes-response trials, participants may have frequently attributed the probe's membership in the current target set to membership in a previous target set, thereby responding "No" instead of "Yes". Therefore, in a paradigm with frequent stimulus repetitions, participants may take longer to reach the level of confidence required to make a correct "Yes" response than in a paradigm with no repetitions.

Aside from our primary findings regarding the facilitation of interference resolution, Experiment 2 found specific working memory and emotion reaction time interactions. Data from Experiment 2 indicated that emotional pictures selectively impaired working memory reaction times when the trial required a "No" response. The pictures used in Experiment 2 were detailed graphic scenes that were often offensive and disgusting (e.g., mutilation). It is thus likely that the longer reaction times to these Emotional Probe pictures are a product of the graphic and emotionally arousing nature of the pictures themselves, and are independent of working memory processing. Previous studies support this explanation: longer reaction times to negative, highly arousing pictures have been reported in previous research involving both working memory and nonworking memory tasks (Buodo et al., 2002; Fox, Russo, Bowles, & Dutton, 2001; Kensinger & Corkin, 2003; Purcell et al., 1998).

Contrary to our hypothesis that only high arousal would reduce interference in working memory, our results indicate that positive valence, low arousal stimuli also reduces interference in working memory. The reason for this finding is unclear. There is some evidence for different representations for positive and negative valence (Canli, Desmond, Zhao, Glover, & Gabrieli, 1998; Kensinger & Corkin, 2004), which may differentially affect interference resolution processes. Whether such an interaction underlies our findings, however, remains unclear.

In summary, the results from this investigation suggest that emotion has a robust effect on interference resolution in working memory for a range of stimuli. Future experiments will be needed to further clarify emotion's interaction with interference resolution, specifically why facilitation is found for Positive, yet not for Negative Low Arousal stimuli, and what brain regions may mediate the emotion and interference resolution interactions. Nevertheless, when integrated with current emotion and memory literature, these results suggest that although working memory maintenance and capacity components are only selectively influenced by emotion (Kensinger & Corkin, 2003; Perlstein, Elbert, & Stenger, 2002), the executive process involved in conflict resolution are consistently influenced by emotion. Thus each of the various components of working memory seems to interact with emotion independently.

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