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Exposure To A Significant Stressor Simultaneously Enhances Memory For Emotional Aspects
Of An Event And Disrupts Memory For Non-Emotional Aspects Of The Same Event.

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Abstract

The present experiment demonstrates that exposure to a significant stressor simultaneously *enhances* memory for emotional aspects of an event and *disrupts* memory for non-emotional aspects of the same event. These results are consistent with theories invoking differential effects of stress on brain systems responsible for encoding and retrieving emotional memories (the amygdala) and non-emotional memories (the hippocampal formation), and inconsistent with the view that memories formed under traumatic levels of stress are qualitatively the same as those formed under ordinary circumstances (e.g., McNally, 2003; Shobe & Kihlstrom, 1997). These data, which are also consistent with results obtained in a number of studies using animals and humans, have implications for the legal system, clinical practice, and theories regarding human memory.

Exposure To A Significant Stressor Simultaneously Enhances Memory For Emotional Aspects Of An Event And Disrupts Memory For Non-Emotional Aspects Of The Same Event.

The nature of traumatic memory is controversial. Can memories for traumatic events be forgotten for long intervals of time, only to be unearthed or ‘recovered’ years or even decades later? Research addressing ostensibly repressed memories has legal implications and consequently has attracted media attention. Most scientists now agree that true “repression”¹ is rare, but debate continues about what happens to memories formed during high levels of stress. Is memory for traumatic events the same as normal memory, with highly emotional (even highly negative emotional) events simply being better remembered than less emotional events (McNally, 2003; Shobe & Kihlstrom, 1997)? Or, do special mechanisms lead at least some aspects of stressful events to be forgotten? The question, put simply, is whether traumatic memory is “special” (Nadel & Jacobs, 1998; Shobe & Kihlstrom, 1997)?

Shobe and Kihlstrom (1997) argued that “...the preponderance of laboratory evidence indicates that memory is more likely to be enhanced than impaired by high levels of emotion and stress, so that memories for trauma are distinctive, long-lasting, and easily retrieved”. On the other hand, there is evidence that stress differentially affects the various brain regions involved in memory formation, leading to complex patterns of memory disruption and enhancement (Jackson et al., 2004; Nadel & Jacobs, 1998; Payne, Nadel, Britton & Jacobs, 2004).

The key to the controversy may lie in a lack of correspondence between two literatures, one demonstrating that high stress levels *impair* memory (Kim & Diamond, 2002; Lupien & McEwen, 1997; Payne et al., 2004 for reviews), and another demonstrating that negative emotional arousal *enhances* memory (e.g. Reisberg & Heuer, 2004). Negative emotional events

are often quite stressful, so at first glance the two literatures appear to contradict each other. But a closer look reveals that negative emotional arousal has been shown only to facilitate memory for materials that are themselves emotional in nature (e.g. emotionally laden words, graphic pictures).² Similarly, the impairment seen in studies of stress and memory is typically restricted to emotionally neutral materials (de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; Newcomer et al., 1999). Because current views of memory suggest that different aspects of experienced events are processed and stored in different parts of the brain (Schacter & Tulving, 1994), these apparently incompatible findings suggest that stress differentially affects various parts of the brain's memory systems.

Stress-related memory *impairment* is found in studies of memory dependent upon the hippocampus (de Quervain et al., 2003), a brain structure known to be essential for normal episodic memory function. The hippocampus is densely packed with receptors for the stress hormone cortisol, which at high levels disrupts hippocampal function and impairs episodic memory (Kim & Diamond, 2002). Animal work in this area (Lupien & McEwen, 1997) and recent human studies both show the same pattern of memory disruption following exposure to acute stressors (e.g. Jackson, Payne, Nadel & Jacobs, 2004; Payne, Nadel, Allen, Thomas & Jacobs, 2002) or direct administration of cortisol (e.g. de Quervain et al., 2000; Kirschbaum et al., 1996).

Other studies show that emotional arousal, even strongly negative emotional arousal, *enhances* forms of memory dependent on the amygdala (Cahill & McGaugh, 1998). The amygdala plays an important role in memory for emotional events, an effect that is also governed by stress hormones (e.g. norepinephrine) and the beta-adrenergic system (McGaugh, 2000). Until recently it was thought that such arousal had a net facilitating effect on *all* types and *all*

aspects of memory. Livingston's (1967) "Now print!" concept, for example, suggested that the brain 'prints' *all* information immediately preceding and following an arousing event. Similarly, "flashbulb memories", vivid, long-lasting memories for emotionally arousing and significant events, were once thought to strongly and faithfully represent past emotional experience. It appears that neither of these conceptions is completely accurate. Emotional arousal may only facilitate memory for those emotional aspects of events that engender arousal at the time of encoding (Cahill & Alkire, 2003), and flashbulb memories, while maintaining perceived vividness and detail, are often highly inconsistent across time (Talarico & Rubin, 2003).

The present experiment examines the impact of highly emotional, psychosocial stress on multiple types of memory within a single paradigm. We expected to find disruption, preservation, or enhancement depending on the type of information encoded under stress, thus extending findings from the animal literature (Kim & Diamond, 2002) to humans.

To date, most studies of stress and memory have investigated memory for simple word lists and paragraphs (de Quervain et al., 2000). Yet stressful experiences are typically comprised of some combination of emotional features (a person standing next to a wall, threatening you as you walk down the street) and neutral features (the color of the wall, what the person was wearing) unfolding in space and time. It is of theoretical and practical interest to know if stress affects memory for the various aspects of an event in the same way. We thus modified a well-known procedure (Heuer & Reisberg, 1990) to allow memory for neutral and emotional information within a single episode to be evaluated separately. We hypothesized that stress would disrupt memory overall, but we also suspected that analyzing "memory" part by part would reveal a more complex interplay between stress and memory. Specifically, we expected

stress to disrupt neutral but not emotional memory, which would be preserved, if not enhanced, by the same stressor.

METHOD

Participants and Design

Participants were 117 undergraduate students recruited from lower-division psychology classes who received course credit for their participation. Participants were randomly assigned to a 2 (stress group: stress vs. control; between subjects) x 2 (delay condition: immediate memory test vs. 1-week delay; between subjects) x 2 (memory type: neutral information vs. emotional information; within subjects) mixed factorial design. Stress group was the main variable of interest, and consisted of 61 participants in the stress condition (35 females, 26 males) and 56 in the no-stress control condition (29 females, 27 males).

Stimulus Materials

All participants viewed a narrated slideshow containing emotional and neutral information. The slides were taken from Heuer and Reisberg (1990), who kindly provided copies of their materials. Numerous studies have used variations of this procedure to assess the modulatory influence of emotion on memory (e.g. Cahill et al., 1994). Although the Heuer & Reisberg procedure used two different slideshows, one neutral and one emotionally arousing, participants in the present study viewed the emotional version only.

This within-subject procedure offered several advantages over the traditional procedure. First, *all* participants saw and heard identical stimuli, thus eliminating interpretive difficulties posed by the use of different stimuli in the neutral and emotional slideshows. Second, the emotionally arousing slideshow contained rich amounts of *both* neutral and emotional information, permitting us to create measures that assessed neutral and emotional memory

separately. Specifically, the slideshow contained 12 detailed slides, the middle 3 of which were emotionally arousing. The material in the remaining 9 (4 shown before the emotional slides and 5 after) was neutral. Cahill has shown that the middle emotional slides (along with their corresponding narrative) account almost entirely for participants' enhanced memory for the arousing story relative to the neutral story (Cahill & McGaugh, 1995). Heuer and Reisberg (1990) showed the same pattern in their own data, where recognition memory was most pronounced for the emotionally arousing middle slides (see Heuer & Reisberg, Figure 2). The other (emotionally neutral) slides in the arousing version of the story are typically no better remembered than the corresponding slides in the neutral version of the story. Thus, in the present study separate variables were created for emotional and neutral slides in one analysis, and in another, the neutral slides were further broken into "pre" and "post" emotional information. This second variable was created because a recent study suggests that emotional information may cause amnesia for information immediately preceding it (Strange, Hurlmann & Dolan, 2003).

Given the above rationale, all subjects, regardless of experimental condition, viewed a single slideshow with both emotional and neutral content. Each of the 12 slides was accompanied by a recorded narration. The slideshow depicted a mother taking her young son to visit his father (a surgeon) at work. Midway through the slideshow, participants learn that a terrible car accident has occurred, and the father must fight to save the victims. The son watches his father work, and at this point participants see the emotionally arousing slides (the car accident, a team of surgeons operating on the open chest cavity of a victim, and a victim's reattached severed legs).

Procedure

Participants in the experimental group were exposed to the Trier Social Stress Test

(TSST) (Kirschbaum et al. 1993). Participants delivered a speech in front of a one-way mirror. They were told that three trained investigators, located behind the mirror, would evaluate the speech. Ten minutes were given for speech preparation, notes were abruptly taken from participants at the end of this time, and they were asked to give the speech extemporaneously. Participants also believed the speech was video and audio recorded and that verbal and nonverbal aspects of their performance were being analyzed. All speeches were made under intense lighting, in the presence of two tripod-mounted 1000-watt halogen stage lights. Following the 5-minute speech, participants performed a moderately difficult subtraction task aloud, also for 5 minutes. Control participants sat and listened to relaxing music for a corresponding amount of time (ca. 20 minutes).

All participants were tested individually. After completing the TSST (or the relaxation period in the case of controls), participants sat at a computer and two Ag-AgCl electrodes were attached to their fingers. They were told (deceptively) that physiological measurements, including heart rate and skin conductance, were being taken to assess sensitivity to various types of auditory and visual stimulation, that they would be watching a slideshow, that they might find some slides pleasant, some unpleasant and some neutral, and to carefully attend to each slide for the duration of its presentation. After indicating they understood the instructions, participants viewed the slideshow while listening to an accompanying narration through headphones. Each slide was presented for 6 seconds via computer; the narration began immediately after presentation of each slide.

Subjective state anxiety reports (Spielberger, 1983) were collected at 1) the beginning of the experiment, before the experimental manipulation, 2) immediately after the manipulation (participants were asked, “How do you feel *now*?”), 3) after the manipulation, immediately after

the 2nd form (participants were asked, “How did you feel *during* the speech?” and 4) after viewing the slides, at the end of the experiment. Although saliva samples were not analyzed for cortisol content in this study, a sister study (Jackson et al., 2004) demonstrates that, in this laboratory, the TSST reliably elevates cortisol (see also Kirschbaum et al., 1996).

Depending on experimental condition, participants were administered the memory test immediately after viewing the slides or asked to return 2 weeks later for “additional physiological testing”. Neither group was told their memory would be tested during the experiment. Participants in the delay condition were told they were participating in an experiment of sensory sensitivity (e.g. they took home journals to report episodes of sensitivity).

The memory assessment consisted of both a recall and a recognition memory test. Participants were first asked to recall all they could about the narrated story they had previously seen, both about the general story line and any details they recalled. They were then reminded that they had seen a total of 12 slides, and were asked to remember each slide in as much detail as possible. Recall data was taped for later transcription and analysis³. Participants were credited with remembering a slide if they described enough visual information that could only be known from having viewed that particular slide (Cahill et al., 1994). Two judges, blind to experimental condition, scored these data. Each judge also scored the data for false recall errors. Memories were considered “false” only if participants recalled information that was clearly not part of the slideshow or narration. Percent agreement between the judges was 90% in both cases.

Participants were given a 4AFC recognition questionnaire (137 questions). The questions and answer choices were read aloud to participants. For each question, a confidence judgment was made, indicating whether the participant was 1 (not at all confident of the answer) to 5 (extremely confident in the answer). The questions pertained to visual elements of the slideshow

as well as the narration. The order of questions was the same for all subjects.

RESULTS

Exposure to the TSST produced a dramatic increase in mean subjective stress ratings (see Table 1). Although stress and control participants gave equivalent stress ratings at the beginning of the experiment, before stressor administration, those in the experimental condition rated themselves as significantly more stressed, both during ($M = 59$) and immediately after ($M = 51$) the speech, than those in the control condition at the same two times ($M_s = 26$ and 27 , respectively). A one-way analysis of variance (ANOVA) confirmed these were significant differences ($F_s(1, 115) = 275$ (during) 163.3 (after), p_s both $< .0001$). The difference between the groups disappeared on the 4th subjective anxiety measure, given shortly before participants left the lab, indicating that subjective stress had returned to baseline by the end of the experiment.

Recognition Memory Overall

Exposure to the stressor significantly disrupted recognition memory overall. A 2 (stress group) \times 2 (sex) \times 2 (delay) ANOVA revealed a main effect of stress condition, $F(1, 109) = 10.31$, $p < .01$. Stressed subjects remembered significantly less information from the slideshow overall than did non-stressed control subjects. This main effect of stress was qualified by a nearly significant 2-way stress group \times sex interaction $F(1, 109) = 2.3$, $p < .1$. Males' recognition memory suffered more under stress than did that of the females, which was roughly equivalent in both stress and control conditions. Independent t-tests confirmed that un-stressed males' recognition memory was significantly better than that of the stressed males, $t(51) = 2.9$, $p < .01$, and equivalent to that of the females. This pattern of results also emerged in analyses correlating subjective anxiety ratings with overall memory performance. As post-manipulation stress ratings

increased, total recognition memory scores decreased, but only in male participants ($r = .43$, $p = .001$) (females, $r = .009$, $p = .95$).

There was also a significant effect of delay. Participants tested immediately after viewing the slides remembered more information than those tested after a one-week delay, $F(1, 115) = 122.24$, $p < .0001$. The delay variable, however, did not interact with the other variables of interest. We thus collapsed across this variable, and all reported findings below should be considered similar in the immediate and delay conditions.

Emotional Vs. Neutral Recognition Memory

We next examined the effect of stress on the type of memory information presented in the different phases of the slideshow by computing recognition memory scores for emotional and neutral information, yielding a 2-level within subjects “memory type” variable. A repeated measures ANOVA revealed main effects of stress, $F(1, 113) = 5.45$, $p = .02$ and memory type, $F(1, 113) = 146.5$, $p < .0001$, and a significant stress by memory type interaction, $F(1, 113) = 4.57$, $p < .05$. As can be seen in Figure 1, and consistent with our predictions, only neutral information suffered under stress. Memory for emotional information, on the other hand was preserved relative to neutral information. Sex differences did not emerge in this analysis.

Strange et al. (2003) report that memory for neutral information suffers when it precedes emotional information. We thus recreated the memory type variable, this time yielding a 3-level variable (neutral pre, emotional, neutral post). The “pre” refers to the neutral content preceding (slides 1-3) and “post” to the neutral material following (slides 8-12) the central emotional slides. Regardless of its position relative to the emotional material, memory for neutral information was impaired and emotional information was preserved under stress $F(1, 112) = 3.37$, $p = .056$ (See Figure 2). To clarify this result, we analyzed the three story phases (neutral pre, emotional,

neutral post) in separate ANOVAs (after Cahill & McGaugh, 1995), which revealed that stressed participants remembered significantly less neutral information in both the pre ($F(1, 113) = 7.8, p < .01$) and post ($F(1, 113) = 5.05, p < .03$) phases but remembered an equivalent amount of information in the emotional phase ($F(1, 113) = .18, p = .67$ ns).

Finally, despite the changes to the Reisberg & Heuer (1990) procedure, we obtained an “emotional memory enhancement effect.” Figure 3 illustrates that emotional information is better remembered (in this case recognized) than neutral memory, both in the immediate memory and the 1-week delay conditions (both $ps < .0001$). Remembering emotional information well does not, however, mean it is remembered accurately. Looking at false memories (defined as confident false recognition responses), a group x sex interaction emerged, $F(1, 113) = 6.69, p = .011$. Females in the stress group produced more false emotional information than females in the control group, $F(1, 62) = 4.5, p = .038$. Correlational analyses revealed that these false emotional memories were positively related to the *details* of the emotional slides (e.g. the color of a door, the number of cars in a particular slide) ($r = .32, p = .010$), not the gist (e.g. general questions about the story line) ($r = .13, p = .30$). This finding did not apply to males, nor did it reach statistical significance for neutral information.

Recall Memory Overall

Similar to the results found for recognition memory, exposure to the stressor significantly disrupted recall memory in males (sex x stress group effect: $F(1, 109) = 4.54, p < .05$). Males’ recall memory suffered more under stress than did that of the females, which was statistically equivalent in both stress and control conditions. Analyses of false recall errors revealed further memory impairments in stressed subjects. Subjects in the stress group recalled more false information than those in the control group, $F(1, 106) = 4.11, p < .05$. This effect was unrelated to

memory type and sex.

Emotional vs. Neutral Recall Memory

Similar to the recognition memory results, emotional information ($M = .81$) was better remembered than neutral information ($M = .66$) (repeated-measures ANOVA, $F(1, 112) = 45.3$, $p < .0001$) and this did not interact with delay condition. As before, emotional information was preserved relative to neutral information, which suffered under stress. The stress-related deficit, however, emerged for neutral information preceding the emotional slides, $F(1, 105) = 4.74$, $p < .05$ ($M_s = .63$ for stressed participants and $.73$ for controls), but not for the neutral information following the emotional slides. Participants in the stress ($M = .807$) and control ($M = .809$) groups remembered an equivalent amount of emotional information.

Although stress did not affect the amount of emotional information recalled, there were group x sex, $F(1, 105) = 6.5$, $p = .012$ and group x sex x delay interactions, $F(1, 105) = 7.72$, $p = .006$. Splitting the data by “delay” showed that the group x sex interaction reached significance only in the 1-week delay condition, $F(1, 50) = 9.3$, $p < .01$ (See figure 4). Independent t-tests confirmed that stressed females recalled significantly more emotional information than stressed males ($p < .01$), and that stressed females recalled significantly more emotional information than control females ($p = .01$). Thus, stress enhanced emotional recall, but only in females.

DISCUSSION

How victims remember trauma has been termed the “most divisive issue facing psychology today” (McNally, 2003). The appellation is well deserved; in the past decade, both cognitive and neuroscientific studies have shown that emotional arousal augments memory (e.g. Cahill & McGaugh, 1998; Reisberg & Heuer, 2004), an effect replicated here. In the debate surrounding the traumatic memory question, data from the many studies demonstrating

emotional memory enhancement are often used to argue that traumatic memories are well remembered. McNally (2003), for example, argues that “...people remember horrific experiences all too well”. But most studies assessing memory for emotional events fail to account for stress, and the possibility that stressful emotional arousal may impair rather than augment certain aspects of memory. Because traumatic events are both emotionally arousing and intensely stressful our intent was to examine memory for emotionally arousing and neutral information as a function of stress.

First, we replicated the emotional memory enhancement effect typically found in similar designs. This facilitation likely depends upon the amygdala and on the release of cortisol and norepinephrine during stressful events (Cahill & McGaugh, 1998). We showed that memory for emotional materials is superior to memory for neutral materials both immediately and after a one week delay. In typical experiments using this design, memory is tested only after a delay, on the assumption that emotion specifically augments consolidation processes (Cahill & McGaugh). Only recently have encoding effects been considered (Cahill, 2003; Hamann, 2001), and our findings add to the burgeoning evidence that emotional arousal acts on both short-term and long-term memory processes.

Second, these data demonstrate that stress has differential impacts on memory for various features or components of an emotional episode. The episode depicted in our slides is complex, containing features presented in different modalities (visual and auditory), and containing both emotional and neutral information – much as would be expected of any stressful episode. We demonstrated that stress has a differential impact on the various features of that episode; central emotional information, as expected, was remembered well but neutral information suffered significantly. According to these findings, stress *can* disrupt memory for certain features of an

emotionally laden episode.

Hence, stress may simultaneously impoverish memory for neutral aspects, and preserve emotional aspects of a traumatic episode. What would such a memory look like when recalled? It certainly would not include a perfect rendition of the original emotional experience. It might be vague for important neutral details, like time of occurrence, or spatial context, or perhaps non-critical details about a perpetrator (e.g. what he or she was wearing), while being relatively sharp for focal emotional information (e.g. the pain of being hurt, the fact that one was raped). Even so, one must keep in mind that some “memories” of “well-remembered” emotional events are inaccurate. A hint of this exists in our own data, albeit only in women, and only in memory for minor emotional details – not emotional gist (see also Payne et al., 2004). It also exists in flashbulb memories, which lack accuracy and consistency even in those memories people believe they remember in sharp detail (e.g. September 11th, Talarico & Rubin, 2003).

In sum, we have shown that stress has a complex effect on memory. Memory for an emotional experience is preserved or even strengthened, but memory for the neutral elements of the emotional experience is diminished. This pattern of results can be readily understood if one assumes that these two aspects of memory depend upon the amygdala and hippocampus respectively, and that a sufficiently high concentration of stress hormones potentiates the former but inhibits the latter. These results should not be surprising. Clinicians often report that memory for trauma is characterized not only by intrusive memories, but also by gaps in memory and general memory impairment (see Payne et al., 2004). Our data suggest that a brain-based account of memory for trauma, taking into account the role of stress hormones and their actions at different memory-relevant locations in the brain, might explain why this is so.

References

- Buchanan, T. W. & Lovallo, W. R. (2001). Enhanced memory for emotional material following stress-level cortisol treatment in humans. *Psychoneuroendocrinology*, 26, 307-317.
- Cahill, L. (2003). Similar neural mechanisms for emotion-induced memory impairment And enhancement. *Proceedings of the National Academy of Sciences USA*, 100, 13123-13124.
- Cahill, L., & Alkire, M. (2003). Epinephrine enhancement of human memory consolidation: Interaction with arousal at encoding. *Neurobiology of Learning and Memory*, 79, 194-198.
- Cahill, L., Gorski, L., & Le, K. (2003). Enhanced human memory consolidation with post-learning stress: Interaction with the degree of arousal at encoding. *Learning & Memory*, 10, 270-274.
- Cahill, L., & McGaugh, J. L. (1995). A novel demonstration of enhanced memory associated with emotional arousal. *Consciousness and Cognition*, 4, 410-421.
- Cahill, L., & McGaugh, J. L. (1998). Mechanisms of emotional arousal and lasting declarative memory. *Trends in Neuroscience*, 21, 294-299.
- Cahill, L., Prins, B., Weber, M., & McGaugh, J. L. (1994). Beta adrenergic activation and memory for emotional events. *Nature*, 371, 702-704.
- de Quervain, D. J., Henke, K., Aerni, A., Treyer, V., McGaugh, J. L., Berthold, T., Nitsch, R. M., Buck, A., Roozendaal, B., & Hock, C. (2003). Glucocorticoid-induced impairment of declarative memory retrieval is associated with reduced blood flow in the medial temporal lobe. *European Journal of Neuroscience*, 17(6), 1296-302.

- de Quervain, D. J., Roozendaal, B., Nitsch, R. M., McGaugh, J. L., & Hock, C. (2000). Acute cortisone administration impairs retrieval of long-term declarative memory in humans. *Nature Neuroscience*, 3, 313-314.
- Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Sciences*, 5, 394-400.
- Heuer, F., & Reisberg, D. (1990). Vivid memories of emotional events: The accuracy of remembered minutiae. *Memory & Cognition*, 18, 496-506.
- Jackson, E. D., Payne, J. D., Nadel, L., & Jacobs, W. J. (submitted). Stress and human memory: Different effects on amygdala- and hippocampal-based systems.
- Kim, J. J. & Diamond, D. M. (2002). The stressed hippocampus, synaptic plasticity and lost memories. *Nature Reviews Neuroscience*, 3, 453-462.
- Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The "Trier Social Stress Test": A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, 28, 76-81.
- Kirschbaum, C., Wolf, O. T., May, M., Wippich, W., & Hellhammer, D. H. (1996). Stress and treatment-induced elevations of cortisol levels associated with impaired declarative memory in healthy adults. *Life Sciences*, 58, 1475-1483.
- Livingston, R. B. (1967). Reinforcement. In G. Quarten, T. Melnechuk, & F. Schmitt (Eds.). *The neurosciences: A study program* (pp. 514-576). Rockefeller Press, NY.
- Lupien, S. J. & McEwen, B. S. (1997). The acute effects of corticosteroids on cognition: Integration of animal and human model studies. *Brain Research Reviews*, 24, 1-27.

- McGaugh, J. L. (2000). Memory – A century of consolidation. *Science*, 287, 248-251.
- McNally, R. J. (2003). *Remembering trauma*. Cambridge, MA: Harvard University Press.
- Nadel, L., & Jacobs, W. J. (1998). Traumatic memory is special. *Current Directions in Psychological Science*, 7, 154-157.
- Newcomer, J. W., Selke, G., Melson, A. K., Hershey, T., Craft, S., Richards, K., et al. (1999) Decreased memory performance in healthy humans induced by stress-level cortisol treatment. *Archives of General Psychiatry*, 56, 527-533.
- Payne, J. D., Nadel, L., Allen, J. J. B., Thomas, K. G. F., & Jacobs, W. J. (2002). The effects of experimentally-induced stress on false recognition. *Memory*, 10, 1-6.
- Payne, J. D., Nadel, L., Britton, W. B., & Jacobs, W. J. (2004). The biopsychology of trauma and memory. In D. Reisberg & P. Hertel (Eds.), *Memory and emotion* (pp. 76-128). London: Oxford University Press.
- Reisberg, D. & Heuer, F. (2004). Memory for emotional events. In D. Reisberg & P. Hertel (Eds.), *Memory and emotion* (pp. 3-41). London: Oxford University Press.
- Schacter, D. L., & Tulving, E. (Eds.), (1994). *Memory systems 1994*. Cambridge, MA: MIT Press.
- Spielberger, C. D. (1983). *Manual for the state-trait anxiety inventory (2nd ed.)*. In collaboration with Gorusch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. Palo Alto, CA: Consulting Psychologists Press.
- Strange, B. A., Hurlmann, R., & Dolan, R. J. (2003). An emotion-induced retrograde amnesia in humans is amygdala- and beta-adrenergic-dependent. *Proceedings of the National Academy of Sciences USA*, 100(23), 13626-31.
- Shobe, K. K., & Kihlstrom, J. F. (1997). Is traumatic memory special? *Current Directions in*

Psychological Science, 6(3), 70-74.

Talarico, J. M., & Rubin, D. C. (2003). Confidence, not consistency, characterizes flashbulb memories. *Psychological Science*, 14, 455-461.

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Footnotes

¹ Scientists largely agree that the data have not produced substantial evidence for repression in the Freudian sense of unintentionally forgetting entire experiences that are too threatening for the ego to bear (e.g. Holmes, 1990).

² The same is true for stress hormones administered directly' Buchanan & Lovallo (2001), and for a physical stressor administered following presentation of emotional stimuli (Cahill, Gorski & Le, 2003). These studies assessed memory for neutral vs. arousing *pictures*, whereas the current study assessed memory for *episodes*.

³ With the exception of 4 subjects, who were excluded from the analysis due to problems with the recording equipment.

Figure Captions

Figure 1. Recognition memory for neutral and emotional slides: proportion of questions correctly answered by stress and control groups. * $p < .05$

Figure 2. Recognition memory for different slides: proportion of questions correctly answered by stress and control groups. * $p < .05$

Figure 3. Recognition memory for different slides: proportion of questions correctly answered by immediate and one-week delay groups.

Figure 4. Recall for emotional slides in male and female participants.

Table 1

Mean subjective stress ratings at the 4 different time points during the experiment.

	1st Speilberger, before manipulation.	2nd Speilberger, after manipulation.	3rd Speilberger, “how did you feel during?”.	4th Speilberger, prior to leaving lab.
Control Group	35	27	26	34
Stress Group	37	51	59	36
F-value	3.5	163.3	275.0	1.5
p-value	NS	< .0001	< .0001	NS

Figure 1.

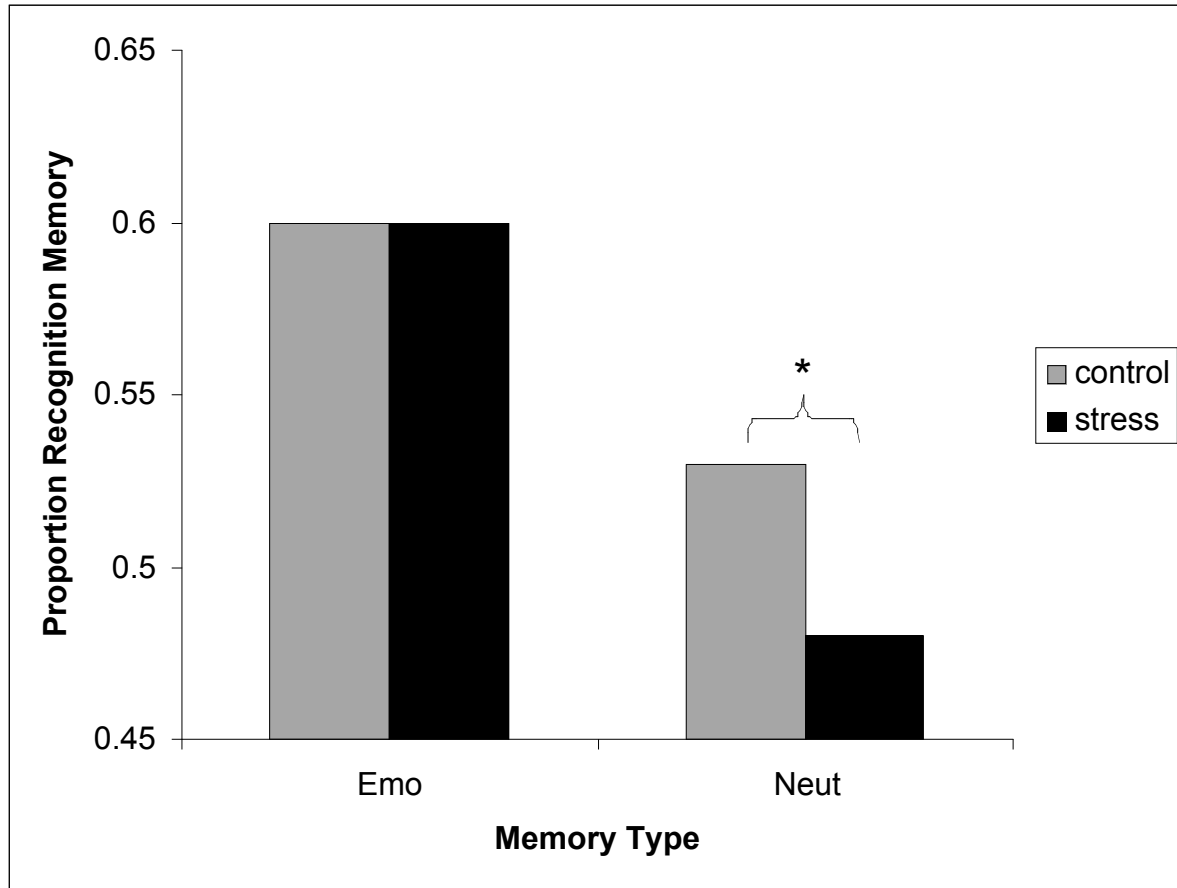


Figure 2.

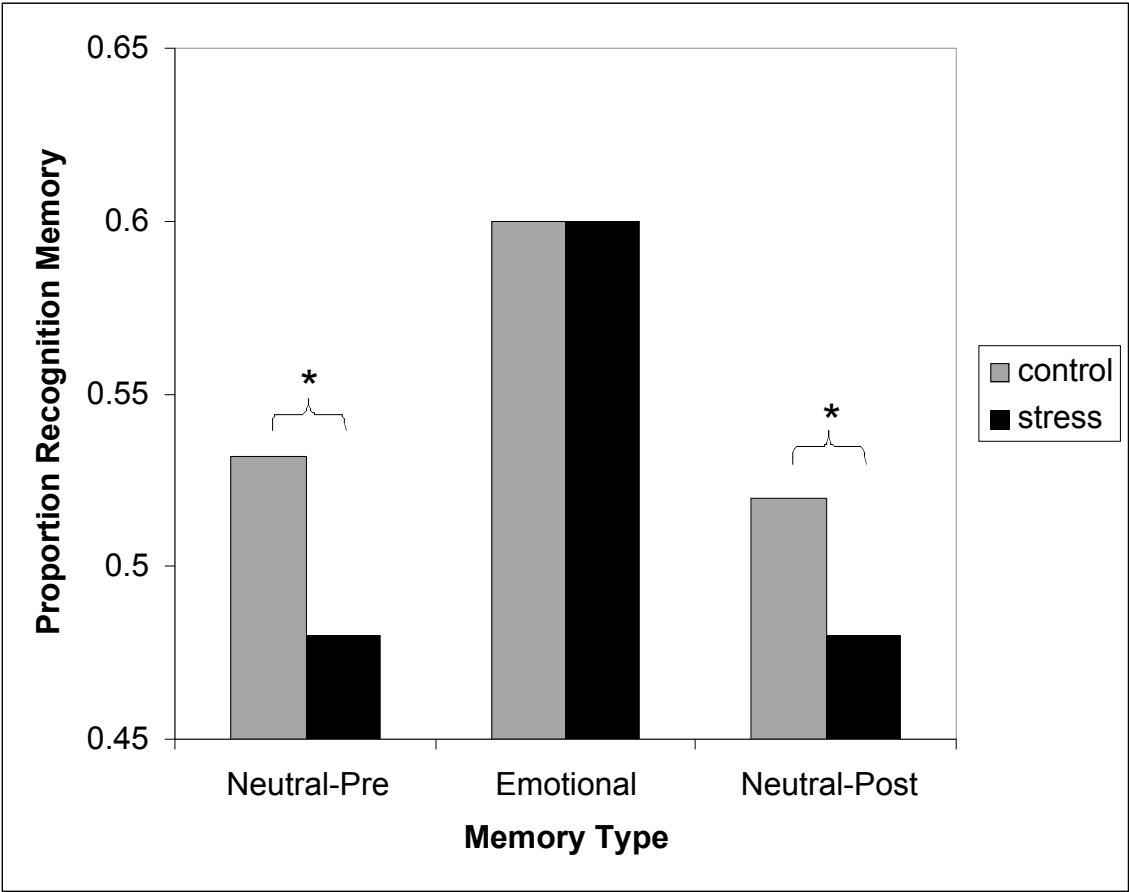


Figure 3.

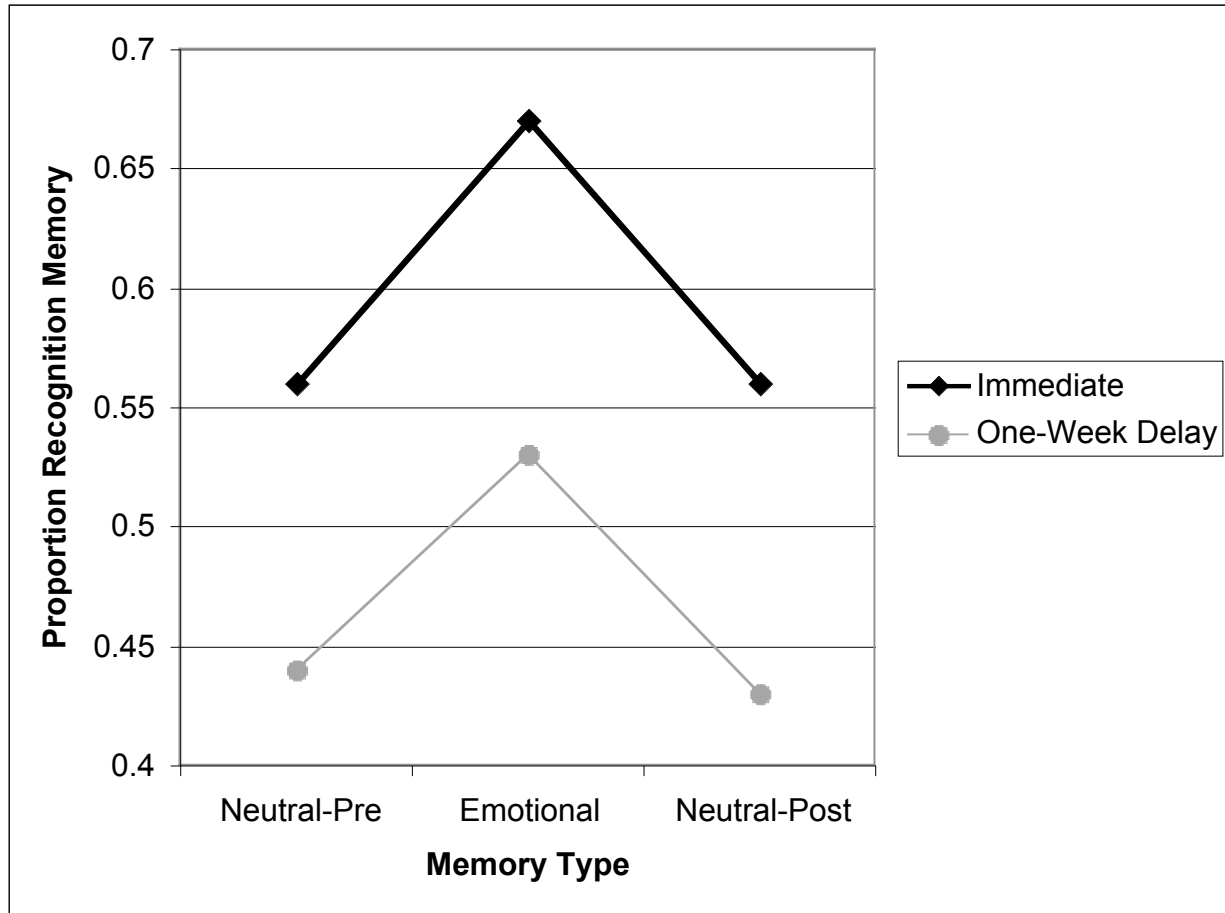


Figure 4.

