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Cold-pressor stress after learning enhances familiarity-based recognition memory in men

Andrew M. McCullough *, Andrew P. Yonelinas

University of California Davis, CA 95616, United States

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ABSTRACT

Stress that is experienced after items have been encoded into memory can protect memories from the effects of forgetting. However, very little is known about how stress impacts recognition memory. The current study investigated how an aversive laboratory stressor (i.e., the cold-pressor test) that occurs after information has been encoded into memory affects subsequent recognition memory in an immediate and a delayed test (i.e., 2-h and 3-month retention interval). Recognition was assessed for negative and neutral photographs using a hybrid remember/know confidence procedure in order to characterize overall performance and to separate recollection- and familiarity-based responses. The results indicated that relative to a non-stress control condition, post-encoding stress significantly improved familiarity but not recollection-based recognition memory or free recall. The beneficial effects of stress were observed in males for negative and neutral materials at both immediate and long-term delays, but were not significant in females. The results indicate that aversive stress can have long-lasting beneficial effects on the memory strength of information encountered prior to the stressful event.

1. Introduction

Stress can impact memory in various ways (Joëls, Pu, Wiegert, Oitzl, & Krugers, 2006; Lupien & McEwen, 1997; McGaugh & Roozendaal, 2002; Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012). For example, chronic stress can lead to permanent impairments in long term memory (McEwen & Sapolsky, 1995), and acute stress encountered during or just prior to retrieval can lead to decrements in memory performance (e.g., Schwabe, Wolf, & Oitzl, 2010; Smeets, Otgaar, Candel, & Wolf, 2008). However, there is growing evidence that acute stress encountered shortly after encoding can have *beneficial* effects on free recall, in the sense that post-encoding stress can protect memories from the effects of forgetting (Andreano & Cahill, 2006; Cahill, Gorski, & Le, 2003; Smeets et al., 2008). The beneficial effects of stress during the retention interval are theoretically important because they provide evidence for a consolidation process whereby stress acts to protect or strengthen recently encoded memories (e.g., McGaugh, 2000; Schwabe et al., 2012).

However, whether stress has a direct impact on memory strength is unclear because in almost all of the previous studies of post-encoding stress only free recall was measured rather than recognition memory. Stress may increase recall performance by facilitating the retrieval or search processes that are critical for recall without directly impacting the strength of the underlying memory trace. In the only study that has examined the effects of stress on recognition (Yonelinas, Parks, Koen, Jorgenson, & Mendoza, 2011) subjects encoded a mixture of negative and neutral photographs, then either went skydiving or waited on the ground. After a 2-h delay period, free recall and recognition memory were tested. Recognition was tested using a remember/know and confidence rating procedure in order to separate recollection and familiarity-based recognition. The results indicated that stress led to an increase in familiarity-based recognition memory, and did not impact recollection-based recognition or free recall. In addition, the beneficial effects of stress were observed in males but not in females, a finding that is consistent with prior studies in humans and animals (e.g., Andreano & Cahill, 2006; Cazakoff, Johnson, & Howland, 2010; Conrad et al., 2004), and that has been attributed to variations in hormonal levels across the estrus cycle (for a review, see Andreano & Cahill, 2009).

The results of Yonelinas et al. (2011) provide support for the idea that stress facilitates the consolidation of recently encoded memories, in the sense that stress influenced familiarity strength, but they raise a number of important questions. First, do the effects of skydiving on recognition generalize to other forms of stress? Skydiving is unusual in that subjects are willing to pay for the experience, and it is a very extreme stress manipulation. That is, the cortisol elevations reported in the skydiving study were about two times the magnitude of those reported in most laboratory

* Corresponding author. Address: University of California Davis, Department of Psychology, One Shields Avenue, Davis, CA 95616, United States.
E-mail address: amccullough@ucdavis.edu (A.M. McCullough).

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studies of stress and memory which have used either the cold-pressor test, in which an arm is held in ice water, or various types of socially-induced stress. Whether recognition memory performance benefits from a stressor such as the cold-pressor test is unknown.

Second, an unexpected finding in the skydiving study was that while stress improved memory for neutral materials, it did not significantly affect memory for negative materials. This contrasts with several previous studies of recall which suggested that stress has larger effects on negative than neutral materials (e.g., Cahill et al., 2003; Smeets et al., 2008). Importantly, memory performance for negative materials was quite high in the study by Yonelinas et al. (2011), and so high levels of performance may have concealed effects of stress on memory for negative materials.

Third, to what degree is the stress-related enhancement of memory maintained across time? Yonelinas et al. (2011) tested memory 2 h after the stressor (a time that was sufficient to allow cortisol levels to return to normal levels), and found that stress affected familiarity-based recognition, but not recollection or recall. However, prior studies reporting effects of stress on recall have used longer delays, such as 1 day (Smeets et al., 2008), 48 h (Beckner, Tucker, Delville, & Mohr, 2006), or 1 week (Cahill et al., 2003). Whether the beneficial effects of stress on familiarity-based recognition are maintained across a longer delay is unknown. Moreover, it is possible that the beneficial effects of stress on recollection and recall simply require more time to emerge. Thus, it is critical to determine the effects of stress across short and long delays.

The current study examined the effect of post-encoding stress on recognition, using the cold-pressor test. The primary questions were whether recollection or familiarity would be enhanced by post-encoding stress induced by the cold-pressor test, whether stress would benefit memory for both negative and neutral materials, and whether any such effects would be maintained across a long retention interval. In addition, because prior studies have indicated that the stress effects are more robust for males than for females (e.g., Andreano & Cahill, 2006) we included both males and females to determine if the stress effects were modulated by sex. Participants first encoded negative and neutral pictures, then completed either a stress-induction procedure (i.e., cold-pressor with ice water) or a non-stress control procedure (i.e., warm water). After a 2 h delay, recall and recognition for the pictures was tested. To reduce possible ceiling effects, the presentation rate during the study phase was shorter than that used by Yonelinas et al. (2011; i.e., 800 vs. 2000 ms/image). A remember/know confidence procedure was used to separate the effects on recollection and familiarity-based recognition. Finally, subjects were brought back to the lab several months later and received a second set of recall and recognition tests for the originally-encoded target materials.

2. Methods

2.1. Participants

A total of 40 undergraduates (20 female) were recruited from an online participant pool, and received Psychology course credit for participating. All testing was conducted between 11:00 and 15:00 h. We chose the 11:00–15:00 testing period to avoid the rapid decline of cortisol associated with waking up (Lommer et al., 1976), and to facilitate comparisons to other related studies that had tested at this time (e.g., Yonelinas et al., 2011). Twenty subjects (10 female) were assigned to the stress group (Mean age = 19.2 years, Mean years education = 13) and twenty (10 female) were assigned to the control group (Mean age = 19.7 years, Mean years education = 13.5). Three participants reported use of oral contraceptives (1 stress, 2 controls), but excluding these subjects did not influence the pattern of results. All 40 subjects were contacted for a follow-up session. Twenty-one subjects (11 female) returned for the long-term memory assessment, for which they were paid $30. Ten had been originally assigned to the control condition (5 female), and eleven had been assigned to the stress condition (6 female). None of our subjects reported use of tobacco or medications. The study was approved by the Internal Review Board at the University of California, Davis.

2.2. Stimuli

The current study used a set of 368 pictures, half neutral and half negative, that was used in previous research (Yonelinas et al., 2011). The pictures were selected primarily from the International Affective Photo Series (IAPS) based on their standard scores of emotional arousal and emotional valence (Lang, Bradley, & Cuthbert, 2008), as well as from our own set (to balance the two sets for factors such as visual complexity, color, and the presence of humans). Images were approximately 315 pixels square, with minor variation in size and shape. Eight of the images were used as example trials: two prior to encoding and six prior to the recognition task. In the encoding phase, 60 neutral and 60 negative pictures were presented to each participant in a random order. In the initial recognition test, each participant was presented with 120 studied images and 120 new images (60 neutral) in a random order. Participants who returned for the long-term assessment were presented with the 120 studied images and the remaining 120 new images (60 neutral).

2.3. Procedure

The procedure is illustrated in Fig. 1. After providing informed consent, participants provided a baseline saliva sample. The participant was offered a piece of gum and produced approximately 3 mL of saliva into a Salivette tube. Then the participant completed an incidental encoding procedure, in which 120 IAPS pictures (60 neutral, 60 negative) were presented via computer (using e-Prime 2.0) and the participant rated each picture for visual complexity. Each picture was presented for 800 ms, after which the participant had up to 2000 ms to respond. After an inter-trial interval of 500 ms, the next trial was initiated. These ratings were not analyzed. The participant completed questionnaires for approximately 10 min, providing demographic, medical, and sleep-related information.

Each participant then completed the cold-pressor test or a control task. The participant submerged their non-dominant arm in either an ice-water bath (M = 0.6 °C) or tepid water (M = 23.4 °C). The participant was instructed to keep their arm submerged for 3 min, or as long as possible, and to refrain from talking during the task. After a 20 min delay, a second saliva sample was taken. This was followed by a 1 h delay before a third saliva sample was taken. During the delay period, the participant was permitted to drink water (but not to eat), and was permitted to read or complete course work so long as it did not involve viewing pictures. Finally, the participant completed a recall and a recognition test.

The participant was given 10 min to recall as many pictures as possible by writing short descriptions of studied pictures. The recall test was followed immediately by a recognition test in which a mix of 120 studied and 120 new pictures were presented for 1500 ms each. Participants rated each picture as either being Recollected, or on a scale of 1–5, in which 1 = *Sure new* and 5 = *Sure old*. After the participant responded, a 500 ms interval preceded the subsequent trial.

For the long-term assessment, the testing procedure was identical to the initial test phase. That is, upon arriving to the lab and giving informed consent, participants were given 10 min to recall