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# Brief, pre-learning stress reduces false memory production and enhances true memory selectively in females

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## HIGHLIGHTS

- Brief, pre-learning stress reduces false memory recall in males and females.
- Stress enhances true memory in females, but not males.
- Temporal effects of stress on false memory depend on sex.

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## ABSTRACT

Some of the previous research on stress–memory interactions has suggested that stress increases the production of false memories. However, as accumulating work has shown that the effects of stress on learning and memory depend critically on the timing of the stressor, we hypothesized that brief stress administered immediately before learning would reduce, rather than increase, false memory production. In the present study, participants submerged their dominant hand in a bath of ice cold water (stress) or sat quietly (no stress) for 3 min. Then, participants completed a short-term memory task, the Deese–Roediger–McDermott paradigm, in which they were presented with 10 different lists of semantically related words (e.g., candy, sour, sugar) and, after each list, were tested for their memory of presented words (e.g., candy), non-presented unrelated "distractor" words (e.g., hat), and non-presented semantically related "critical lure" words (e.g., sweet). Stress, overall, significantly reduced the number of critical lures recalled (i.e., false memory) by participants. In addition, stress enhanced memory for the presented words (i.e., true memory) in female, but not male, participants. These findings reveal that stress does not unequivocally enhance false memory production and that the timing of the stressor is an important variable that could mediate such effects. Such results could have important implications for understanding the dependability of eyewitness accounts of events that are observed following stress.


## 1. Introduction

Stress exerts complex effects on cognition. On one hand, stress can produce powerful memories that last a lifetime, while on the other hand, stress can be distracting and debilitating and cause us to forget important details in our everyday lives. Much of the initial research in the area of stress and cognition reported deleterious effects of stress on learning and memory [1,2]; however, over the past decade, a significant amount of laboratory research has shown that stress can enhance, impair or have no effect on such processes, depending on several factors [3,4]. For instance, the stage of learning and memory that is influenced by stress plays a large role in dictating the types of effects that are observed. Post-learning stress often facilitates long-term memory, while pre-learning and pre-retrieval stress effects are more variable and can involve enhancements or impairments of memory [5,6]. Regardless of the direction of effect observed, the influence of stress on learning and memory is largely due to stress-induced amygdala modulation of cognitive brain structures, such as the hippocampus and prefrontal cortex (PFC) [6,7]. Specifically, stress-induced increases in glucocorticoids and norepinephrine fuel the amygdala to either facilitate or impair processing in these brain areas.

Learning and memory are dynamic, constructive processes. Therefore, when we acquire or remember information, it is by no means

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similar to a tape recorder or the playback thereof. This topic has been particularly salient with regard to the accuracy of eyewitness accounts, and with relation to stress, investigators have been interested in how high states of arousal, such as those that occur when witnessing a crime, influence an observer's memory for the event [8]. Laboratory investigations of the effects of stress on eyewitness accounts have frequently revealed that stress can reduce memory accuracy and impair one's ability to identify the correct suspect for a crime [9]. In addition, more basic research examining the effects of stress on false memory (e.g., memory for words not presented in a word list) production has sometimes indicated that stress increases false recollections. In these studies, investigators have often used what is known as the Deese–Roediger–McDermott (DRM) paradigm to assess false memory [10,11]. This paradigm involves exposing participants to lists of semantically-related words (e.g., bed, rest, awake, tired) that are all associated with a non-presented "critical lure" word (e.g., sleep). Following word list exposure, participants often falsely recall or recognize the non-presented critical lure as being a part of the word list that was originally observed, effects that are presumed to occur as a result of failed source monitoring. Although the DRM paradigm does not involve an event that is witnessed and then recalled by participants, it still allows investigators to gain insight into the mechanisms underlying false memory production and the factors that could influence it. Such examinations could shed light on why eyewitnesses of a crime falsely remember details that were never actually observed. Indeed, some research has reported a positive relationship between false memory in the DRM paradigm and errors of commission on misleading questions and distortions in autobiographical memory [12,13]. Studies examining stress effects on DRM paradigm performance, however, have reported mixed results. For instance, Payne and colleagues were the first to report that stress increased participants' false recognition of the critical lures in the DRM paradigm [14]. However, three subsequent studies found that stress had no effect on false recall or recognition in the DRM paradigm [15–17], and one study reported a reduction of false memories when cortisol was administered prior to retrieval (note, however, that this study also reported a deleterious effect of cortisol on true memory) [18]. Thus, it is unclear as to what factors might mediate the differential effects of stress on false memory in a laboratory setting.

Recent work on stress and memory has fostered an appreciation for the influence that the timing of the stress relative to learning can have on memory formation. For instance, Diamond and colleagues contended that stress rapidly activates the amygdala, which results in enhanced hippocampal neuroplasticity and improved learning and memory; however, as time passes, the stressor causes hippocampal function to enter a refractory period, during which synaptic plasticity and learning are impaired [4]. This "temporal dynamics model" was based largely on research showing that glucocorticoids, as well as electrical stimulation of the amygdala, could exert immediate excitatory, but delayed inhibitory, effects on hippocampal synaptic plasticity [19–23]. Indeed, a general consensus has begun to emerge suggesting that if a brief stressor is administered in close proximity to learning, then long-term memory should be enhanced. This line of reasoning has stemmed from a plethora of studies reporting rapid, excitatory non-genomic effects of glucocorticoids on hippocampal function [24]. Thus, we speculated that if a brief stressor was administered immediately before the DRM paradigm, memory accuracy might be increased.

The purpose of the present study was to examine the influence of brief stress that was administered immediately prior to learning on false recall and recognition of critical lures from the DRM paradigm. Participants were exposed to stress or a control manipulation and then learned several word lists from the DRM paradigm, one at a time. Following the presentation of each word list, participants' short-term memory for presented and non-presented (i.e., critical lures) words was tested. Based on the ideas discussed above, we hypothesized that true memory (i.e., memory for the presented words) would be enhanced by stress, while false memory (i.e., memory for the critical lures) would be reduced.

## 2. Material and methods

### 2.1. Participants

Sixty students (30 males, 30 females; mean age = 19.18 years) from Ohio Northern University participated in the present study. Individuals were excluded from participating if they met any of the following conditions: diagnosis of Raynaud's disease or peripheral vascular disease; presence of skin diseases, such as severe psoriasis, eczema, or scleroderma; history of syncope or vasovagal response to stress; history of severe head injury; current treatment with psychotropic medications, narcotics, beta-blockers, steroids, or any other medication that was deemed to significantly affect central nervous or endocrine system function; mental or substance use disorder; regular nightshift work. Individuals who smoked were allowed to participate in the study; information regarding individuals' smoking habits was collected prior to the experiments via a short demographic survey. There were only 2 participants who reported smoking on a regular basis, and inclusion of the data from these participants in the statistical analyses did not alter the results. Females who took birth control on a regular basis were also allowed to participate in the study; prior to participation, we asked female participants if they took birth control via the short demographic survey. Females who reportedly took birth control were not significantly different from naturally cycling females on any physiological or behavioral measure, nor did stress significantly interact with birth control in these analyses. Therefore, we treated all females as a single group in the statistical analyses for this study. Participants were asked to refrain from using recreational drugs (e.g., marijuana) for three days prior to the experimental sessions; to refrain from drinking alcohol or engaging in strenuous exercise for 24 h prior to the experimental sessions; and to refrain from eating or drinking anything but water for 2 h prior to the experimental sessions. Participants were awarded class credit upon completion of the study. All of the methods for the experiment were approved by the Institutional Review Board at Ohio Northern University.

### 2.2. Experimental procedures

The experimental timeline for the present experiment is presented in Fig. 1. To control for diurnal variations in cortisol levels, all testing was carried out between 1100 and 1800 h.

#### 2.2.1. Cold pressor test (CPT)

Participants were randomly assigned to a stress or no stress condition. Participants who were randomly assigned to the stress condition (N = 30, 15 males, 15 females) submerged their dominant hand, up to and including the wrist, in a bath of ice cold (0–2 °C) water for 3 min. The water was maintained at the appropriate temperature by a VWR 1160S circulating water bath. To maximize the stress response, participants were encouraged to keep their hand in the water bath for the entire 3-min period. However, if a participant found the water bath to be too painful, he or she was allowed to remove his or her hand from the water and continue with the experiment. Only 2 participants removed their hand from the water prior to 3 min elapsing (mean water time = 172.20 s). Participants who were randomly assigned to the no stress condition sat quietly for the same amount of time.

#### 2.2.2. Subjective stress rating

Following the CPT or control condition, participants were asked to rate the stressfulness of the task on an 11-point scale ranging from 0 to 10, with 0 indicating a complete lack of stress and 10 indicating unbearable stress.