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The effect of mild acute stress during memory consolidation on emotional recognition memory

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ABSTRACT

Stress during consolidation improves recognition memory performance. Generally, this memory benefit is greater for emotionally arousing stimuli than neutral stimuli. The strength of the stressor also plays a role in memory performance, with memory performance improving up to a moderate level of stress and thereafter worsening. As our daily stressors are generally minimal in strength, we chose to induce mild acute stress to determine its effect on memory performance. In the current study, we investigated if mild acute stress during consolidation improves memory performance for emotionally arousing images. To investigate this, we had participants encode highly arousing negative, minimally arousing negative, and neutral images. We induced stress using the Montreal Imaging Stress Task (MIST) in half of the participants and a control task to the other half of the participants directly after encoding (i.e. during consolidation) and tested recognition 48 h later. We found no difference in memory performance between the stress and control group. We found a graded pattern among confidence, with responders in the stress group having the least amount of confidence in their hits and controls having the most. Across groups, we found highly arousing negative images were better remembered than minimally arousing negative or neutral images. Although stress did not affect memory accuracy, responders, as defined by cortisol reactivity, were less confident in their decisions. Our results suggest that the daily stressors humans experience, regardless of their emotional affect, do not have adverse effects on memory.

1. Introduction

Stress is something we all experience at some point in our lives or even on a daily basis and can be broadly defined as our body and brain's response to changing demands. When we feel stress, we experience a set of physiological changes that are collectively known as the stress response. In addition to the physiological changes produced by stress, the stress response also includes changes in the central nervous system (CNS), which have lasting effects on health and cognitive processes (for review, de Kloet, Joels, & Holsboer, 2005). The effects of stress depend on the type of stress experienced. Exposure to chronic stress is generally harmful to health and cognitive processes and can lead to anxiety, depression, high blood pressure and other health issues (for review, de Kloet et al., 2005; McEwen, 2000). While we know that chronic stress is harmful, we know less about the effects of acute stress. Previous studies have resulted in mixed findings on the effects of acute stress on memory, with some finding impairments and some finding improvements (for review, LaBar & Cabeza, 2006; McGaugh, 2000; Shields, Sazma, & Yonelinas, 2016). The direction of the effect appears to depend on multiple factors: the timing of the stressor (for review, Wolf, 2009) the strength of the stressor (Akirav et al., 2004; Diamond, Bennett, Fleshner, & Rose, 1992; Sandi, Loscertales, & Guaza, 1997) and the type of material being encoded (Cahill & Alkire, 2003; Cahill, Gorski, & Le, 2003; Smeets, Otgaar, Candel, & Wolf, 2008). We will discuss each of these factors in turn.

One of the key factors determining whether acute stress will result in improvements or impairments is when the stress is induced (for review, Wolf, 2009). Recognition memory can be separated into three phases: encoding, when information is learned, consolidation, when information is stored and the memory trace is strengthened, and retrieval, when the information is recovered. Stress induced prior to encoding has produced mixed results, with some evidence for memory impairments (Maheu, Collicutt, Kornik, Moszkowski, & Lupien, 2005; Maheu, Joober, Beaulieu, & Lupien, 2004; Preuss & Wolf, 2009; Schwabe & Wolf, 2010) and some evidence for memory improvements (Abercrombie, Kalin, Thurow, Rosenkranz, & Davidson, 2003; Buchanan & Lovallo, 2001; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008). Stress induced prior to retrieval consistently impairs memory

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(Buchanan, Tranel, & Adolphs, 2006; de Quervain, Aerni, & Roozendaal, 2007; de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; de Quervain et al., 2003; Kuhlmann, Piel, & Wolf, 2005; Smeets et al., 2008), while stress induced during consolidation consistently enhances memory (Beckner, Tucker, Delville, & Mohr, 2006; Cahill et al., 2003; Preuss & Wolf, 2009; Smeets et al., 2008). One of the first studies in humans to suggest that acute stress during consolidation can be beneficial to memory was a study that administered the cold pressor task (CPT) immediately following learning (Cahill et al., 2003). Subjects were presented with emotionally arousing negative or neutral images and then immediately submerged their hand in ice cold (stress group) or warm (control group) water for 1–3 min. Their recall was tested one week later. Participants who were administered the CPT had higher recall for the emotionally arousing negative images than participants who were administered the control task. Although the mechanism by which stress affects memory consolidation in humans has not been determined, rodent literature suggests that stress results in the immediate release of epinephrine from the adrenal medulla and glucocorticoids (cortisol in humans) from the adrenal cortex. Following its release, epinephrine induces an increase in noradrenergic activity in the basolateral nucleus of the amygdala (BLA). Together this BLA activity and the glucocorticoid activity enhance long-term potentiation (LTP) in the hippocampus and amygdala, subsequently enhancing memory consolidation (for review, Cahill et al., 2003; McGaugh & Roozendaal, 2002; Wolf, 2008).

Another factor that determines whether acute stress will result in improvements or impairments in recognition memory is the strength of the stressor. Animal research has suggested a curvilinear relationship between stress level and performance, in which moderate levels of stress improves performance while mild and severe levels of stress may not (Akirav et al., 2004; Diamond et al., 1992; Sandi et al., 1997). Yerkes and Dodson were the first to observe this relationship (Yerkes & Dodson, 1908). In their study, rats were put in front of two rooms, one black and one white, and had to choose which room to enter. If they chose the black room they were given either a mild, moderate or strong electrical shock. As voltage increased, so did learning, but once the voltage passed the moderate level, rats' performance significantly decreased. Animal research suggests that moderate acute stress leads to elevated levels of glucocorticoids that effectively induce LTP and lead to enhanced memory performance. Whereas, severe acute stress leads to abnormal levels of glucocorticoids that impair LTP and subsequently impair memory performance (for review, de Kloet et al., 2005). A similar curvilinear relationship between stress level and performance has been found in humans. Andreano and Cahill (2006) administered CPT to male and female participants immediately after having them read a neutral story and tested their retention of this story 1 week later. Male participants with a moderate increase in cortisol had the highest subsequent memory performance relative to participants with low or high increases in cortisol. Although moderate levels of stress have been suggested to be optimal with regard to memory performance, it is important to understand the effects of mild acute stress since it is more consistent with what humans encounter on a daily basis (i.e. difficult homework, an argument). Understanding the relationship between mild levels of stress and memory performance is one of the goals of the present study.

Another factor that has not been thoroughly assessed in stress studies in humans, but is a key factor in determining how well an event will be remembered, is the type of material being encoded. Long-term memory for emotional events is superior to memory for neutral events (for review, Talmi et al., 2013). Emotion can be defined in terms of valence and arousal. Valence refers to how positive or negative an event is, while arousal indicates the intensity of the emotion (Lang, Greenwald, Bradley, & Hamm, 1993; Russell, 1980). The degree of arousal, rather than valence, is thought to be the primary factor underlying emotion-related memory benefits (Cahill & Alkire, 2003; Dolcos, LaBar, & Cabeza, 2004b; Kensinger & Schacter, 2005; Nielson & Powless, 2007; Smeets et al., 2008). The "modulation hypothesis of emotional memory" states that arousing materials exert their beneficial effect on memory by enhancing activity in both the amygdala and the medial temporal lobe (MTL) memory system, thereby modulating memory consolidation (Dolcos et al., 2004b). Because emotional arousal and stress both independently enhance activity in the amygdala, in combination they are thought to selectively modulate memory consolidation, such that highly arousing negative stimuli will be better remembered relative to minimally arousing negative and neutral stimuli (Cahill & Alkire, 2003; Cahill et al., 2003; Smeets et al., 2008).

Typically, stress studies have used either the Trier Social Stress Task (Kirschbaum, Pirke, & Hellhammer, 1993), which has participants give a speech and do mental math in front of an audience (Abercrombie, Speck, & Monticelli, 2006; Preuss & Wolf, 2009), or the CPT (Cahill et al., 2003; Smeets et al., 2008). An issue with these stressors is that they cannot readily be used in fMRI studies. Having a stress task that can be incorporated into fMRI studies is very important as researchers attempt to understand the neural underpinnings of stress-related memory enhancements. We chose to use the Montreal Imaging Stress Task (MIST), a stress task designed to be used in an fMRI scanner, as our stressor in the current study. The MIST is used to induce mild psychological stress in the laboratory (Dedovic et al., 2005). In the stress condition, the MIST requires participants to complete mental math problems faster than they are able to solve and input their answers. Stress participants also receive negative feedback from the experimenter in between runs. As levels of stress in humans have not been specifically defined, in terms of cortisol response or by the type of stressor, we are defining the MIST as a mild stressor because it usually results in small increases in cortisol relative to other stressors. The MIST typically increases cortisol 50–100% above baseline, whereas the TSST consistently produces increases in cortisol about 200–400% above baseline (Dedovic et al., 2005; Kirschbaum et al., 1993). In order to assess the feasibility of the MIST, we chose to first assess it behaviorally before incorporating it into any of our fMRI studies.

The goal of the current study was to determine the effect of mild acute stress during consolidation for emotional events. To be consistent with previous studies, we measured the stress response by assaying salivary cortisol levels (Andreano & Cahill, 2006; Cahill et al., 2003; Dedovic et al., 2009; McCullough, Ritchey, Ranganath, & Yonelinas, 2015; for review, Shields, Sazma, McCullough, & Yonelinas, 2017). We chose to only include male participants because of known sex differences in HPA axis functioning (Kajantie & Phillips, 2006; Kudielka & Kirschbaum, 2005). Specifically, a woman's menstrual phase and the use of oral contraceptives can affect her cortisol response to stressors (Kajantie & Phillips, 2006). Excluding female participants reduces the variability in the cortisol data and is consistent with previous stress studies that have only used male participants (Abercrombie et al., 2003; de Quervain et al., 2003; Khalili-Mahani, Dedovic, Engert, Pruessner, & Pruessner, 2010; Maheu et al., 2004, 2005; Oei et al., 2007; Pruessner et al., 2008; Schwabe, Romer, et al., 2009). While moderate acute stress during consolidation appears to be optimal for later memory performance, the effects of mild acute stress during consolidation in humans is unknown. We hypothesize that memory for highly arousing negative material has the greatest likelihood of being enhanced by mild acute stress during consolidation. To investigate this, we had participants encode highly arousing negative images, minimally arousing negative images and neutral images. We administered a