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Context-dependent enhancement of declarative memory performance following acute psychosocial stress

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Abstract

Studies on how acute stress affects learning and memory have yielded inconsistent findings, with some studies reporting enhancing effects while others report impairing effects. Recently, Joëls et al. [Joëls, M., Pu, Z., Wiegert, O., Oitzl, M.S., Krugers, H.J., 2006. Learning under stress: how does it work? Trends in Cognitive Sciences, 10, 152–158] argued that stress will enhance memory only when the memory acquisition phase and stressor share the same spatiotemporal context (i.e., context-congruency). The current study tested this hypothesis by looking at whether context-congruent stress enhances declarative memory performance. Undergraduates were assigned to a *personality stress* group ($n = 16$), a *memory stress* group ($n = 18$), or a *no-stress control* group ($n = 18$). While being exposed to the acute stressor or a control task, participants encoded personality- and memory-related words and were tested for free recall 24 h later. Relative to controls, stress significantly enhanced recall of context-congruent words, but only for personality words. This suggests that acute stress may strengthen the consolidation of memory material when the stressor matches the to-be-remembered information in place and time.

Keywords: Acute stress; Glucocorticoids (GCs); Trier Social Stress Test (TSST); Context; Declarative memory

Most people are familiar with highly stressful events. Exposure to such events is known to trigger a variety of physiological reactions, of which many are related to the activation of stress-responsive sympathoadrenal medullary (SAM) and hypothalamic–pituitary–adrenal (HPA) axes. A plethora of research has revealed that secretion of glucocorticoids (GCs) due to HPA axis stimulation may modulate memory functioning (e.g., de Kloet et al., 1999; McGaugh, 2000; Roozendaal, 2000). However, the precise direction of stress-induced GC effects on memory performance is far from clear. Animal studies, for example, have shown that GCs can have facilitating (e.g., on aversive conditioning), but also impairing effects on memory (e.g., de Kloet et al., 1999; Lupien and McEwen, 1997; McGaugh and Roozendaal, 2002). Similarly, studies relying on human participants have reported that acute GC administration may enhance or disrupt memory, yet the precise conditions under which these effects occur are ill-understood (for reviews, see Het et al., 2005; Lupien et al., 2005; Lupien and Lepage, 2001; Wolf, 2003).

One critical variable identified so far is the timing of GC administration or stress exposure. When participants are exposed to acute stress or given GCs prior to the memory retrieval phase, a significant decrease in memory performance is noted (de Quervain et al., 2000; Wolf et al., 2004). Moreover, the effects of GC administration or stress exposure on memory performance also depend on the valence of the material being studied (e.g., Jelicic et al., 2004; Kuhlmann et al., 2005a,b; Smeets et al., 2006; Tops et al., 2003). That is, when applied prior to encoding and recall is tested immediately afterwards, acute stress or GC administration generally impairs memory for neutral stimuli while memory for emotionally positive and negative stimuli appears to be relatively immune to these detrimental effects. On the other hand, when stress or GC administration is employed after consolidation has taken place and delayed recall tests are used, emotional stimuli tend to be impaired more so than neutral ones. On a related note, emotional arousal elicited by the memory material is also important (e.g., Abercrombie et al., 2006; Kuhlmann and Wolf, 2006). It seems that when the to-be-remembered stimuli elicit high levels of emotional arousal, SAM driven stress responses

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in conjunction with GC stress responses may result in memory facilitation for these stimuli in comparison to memory for neutral, low arousing material.

Although a number of variables that modulate the effects of acute stress on memory performance have been identified, the precise nature of the effects remains unclear and a comprehensive framework that may account for the contradictory findings is lacking. Recently, Joëls et al. (2006) have made a first attempt to formulate such an accommodating framework. These authors propose that stress will only enhance memory performance when two conditions are met: first, exposure to stress must be experienced in the context and around the time of learning and, secondly, the brain regions targeted by GCs released during stress exposure should be the same as those activated by the memory task. Thus, stress will promote learning only when its spatiotemporal context is congruent to the memory material, such as is the case when an individual is stressed due to an upcoming exam and learns the subject matter while being stressed. In addition, the memory enhancing effect will only be apparent when stress impacts on the same brain regions as the task at hand, such as when the psychological stress associated with exams impacts upon the hippocampus and the recall task (i.e., exam) also probes for knowledge that is mainly hippocampal-dependent (e.g., factual knowledge, but not procedural memory).

The present study was specifically designed to test the framework of Joëls et al. (2006). In short, our aim was to determine whether exposure to a psychosocial stressor may indeed prove beneficial to performance on declarative memory tasks that are context-related to the applied stressor. To this end, concurrent with learning a list of words that were personality- and memory-related, participants were exposed to a stress task that was focused either on a personality theme or a memory theme. Twenty-four hours later, delayed recall was assessed and compared to a no-stress control condition. Based on Joëls et al. (2006), we hypothesized that relative to non-stressed controls, participants exposed to the acute stressor would show enhanced delayed recall of words that were in congruence with the theme of the stressor.

1. Methods

1.1. Participants

Our sample consisted of 52 young healthy undergraduate students (13 men, 39 women) with a normal body mass index (BMI). Their mean age was 23.08 years (S.D. = 3.81). Participants were excluded from the study when they suffered from endocrine disorders, cardiovascular diseases, other severe medical illnesses (e.g., fibromyalgia), or were on medications known to affect HPA-axis functioning (except oral contraceptives; see below). Test protocols were approved by the standing ethics committee of the Psychology Faculty of Maastricht University. All participants signed a written informed consent and were given course credit in return for their participation.

1.2. Materials

1.2.1. Profile of Mood States

Subjective stress was measured with the Profile of Mood States (POMS; McNair et al., 1992). The POMS is a widely used self-report measure of typical and persistent mood reactions to current life situations. Participants indicate to what extent they agree with adjectives describing their current mood or feelings on five-point scales (anchors: 0 = *not at all*; 4 = *extremely*). The 32-item POMS consists of five subscales (i.e., depression–dejection, anger–hostility, fatigue–inertia, vigor–activity, and tension–anxiety) from which a total negative mood score can be calculated, with higher POMS scores reflecting very negative mood. The POMS has excellent psychometric properties (Lezak, 2004; McNair et al., 1992). We used two Dutch parallel versions of the POMS which have been proven to be valid and reliable (de Groot, 1991; Wald and Mellenbergh, 1990). These two versions were counterbalanced within and across groups.

1.2.2. Trier Social Stress Test (TSST)

The Trier Social Stress Test (TSST; Kirschbaum et al., 1993) is a valid and reliable procedure to induce cortisol stress responses (e.g., Dickerson and Kemeny, 2004; Kirschbaum et al., 1992). We employed a modified version of the TSST basically consisting of a 5 min preparation period, a 5 min mental arithmetic task, and a 6 min free speech in front of an audience while being videotaped. The TSST was modified in such a way that the topic of the free speech was either personality- or memory-related (see Section 1.3 for more details).

1.2.3. Verbal declarative memory task

Participants were required to listen to 2 word lists of 12 words each, with one list consisting of memory words (e.g., ''knowledge'', ''intellect'') and the other containing personality words (e.g., ''anxious'', ''modest''). Words were chosen from the Affective Norms for English Words (ANEW; Bradley and Lang, 1999) and were unanimously categorized as personality or memory words, respectively, in a pilot study ($N = 10$ undergraduate students). Data drawn from the ANEW normative ratings showed that memory and personality words did not differ with respect to mean valence, arousal, dominance, or word frequency (all $ts < 1$; all $ps > .43$). Word lists were audio taped and played back on a digital voice recorder, thus ensuring that all participants heard the words at the same pace, tone of voice, volume, and intonation. Presentation order of the word lists was counterbalanced within and across groups, and lists were presented on two successive learning trials. Participants were explicitly told that their memory for the words would be tested immediately following presentation of the word lists by means of an immediate free recall task. However, we were primarily interested in a surprise delayed free recall test given to them 24 h later.[1]

1.2.4. Heart rate measurement

Heart rate was monitored continuously using portable transmission devices (Polar® Sport Profi S810i). Heart beats per minute (bpm) were averaged over 5 min intervals beginning with the 5 min before stress exposure or filler task and ending after a 30 min total measurement interval had been completed.

1.2.5. Saliva sampling and biochemical analyses

Cortisol data were obtained with cotton Salivette (Sarstedt®, Etten-Leur, The Netherlands) devices. Saliva samples were not centrifuged and were immediately stored at −40 °C on collection. Salivary free cortisol levels were determined in duplicate by direct radioimmunoassay (University of Liège, Belgium), including a competition reaction between ^{125}iodohistamine-cortisol and anticortisol serum made against the 3-carboxymethyloxime–bovine serum albumin conjugate. After overnight incubation at 4 °C of 50 μl saliva, separation of free and antibody-bound ^{125}iodohistamine-cortisol was performed via a conventional second-antibody method. In order to reduce sources of variability, both samples from each participant were analyzed in the same assay. Mean intra- and inter-assay coefficients of variation were less than 5% and 9%, respectively.

[1] In the current study, we were primarily interested in whether congruency between stressor and the to-be-encoded memory material affects subsequent memory performance. In order to eliminate the effects of acute stress and GC elevations on retrieval processes (e.g., de Quervain et al., 2000), the delayed recall test was administered 24 h after initial learning took place.