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# Stress impairs the reconsolidation of autobiographical memories

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ABSTRACT

Stress enhances memory consolidation, in particular for emotional material. When reactivated, consolidated memories return to a fragile state again and thus require another period of stabilization, called reconsolidation. Rodent studies suggest that memory reconsolidation is impaired by stress. Here we examined in healthy humans the effect of stress on the reconsolidation of autobiographical memories. Participants recalled positive, negative and neutral episodes from their recent past and were afterwards exposed to a stressor (socially evaluated cold pressor test) or a non-arousing control condition. Additional groups of participants were exposed to the stressor without prior memory reactivation or were neither stressed nor asked to recall episodes from their past. Stress after memory reactivation impaired the memory for the neutral episodes 1 week later whereas the subsequent memory for the emotional episodes was not affected by stress after reactivation. Reactivation per se or stress without prior memory reactivation had no effect on memory performance. These findings suggest that the effect of stress on memory reconsolidation is opposite to the stress effect on memory consolidation supporting the view that consolidation and reconsolidation are distinct processes.



## 1. Introduction

Emotionally arousing experiences are well remembered. This has been attributed to facilitating effects of stress hormones such as glucocorticoids (GCs; cortisol in humans) and catecholamines (adrenaline and noradrenaline) on memory consolidation. Indeed, it is well documented that stress or stress hormones shortly after learning enhance subsequent memory performance (Buchanan & Lovallo, 2001; Cahill, Gorski, & Le, 2003; Kuhlmann & Wolf, 2006; for reviews see McGaugh, 2000; Roozendaal, McEwen, & Chattarji, 2009; Wolf, 2009). These effects are particularly strong for emotionally arousing information (Buchanan & Lovallo, 2001; Cahill et al., 2003) suggesting that an activation of the amygdala is required for stress (hormone) effects on memory consolidation (Roozendaal et al., 2009).

In the past decade, the idea that memory consolidation is not a one-time process, which was first expressed more than 40 years ago (Misanin, Miller, & Lewis, 1968; Schneider & Sherman, 1968), has been revitalized (Dudai & Eisenberg, 2004; Nadel, 2000; Nader & Hardt, 2009; Nader, Schafe, & LeDoux, 2000b; Sara, 2000). There is by now ample evidence from animal and human studies indicating that consolidated memories become labile again when they are reactivated and hence require another period of stabilization which is referred to as reconsolidation. During the reconsolidation window reactivated memories can be changed by amnestic agents or behavioral manipulations (Eisenberg & Dudai, 2004; Hupbach, Gomez, Hardt, & Nadel, 2007; Kindt, Soeter, & Vervliet, 2009; Nader, Schafe, & LeDoux, 2000a; Przybyslawski, Roullet, & Sara, 1999; Schwabe & Wolf, 2009a).

Is memory reconsolidation, same as the original consolidation process, affected by stress and GCs? There is some first evidence from rodent studies that stress or GC administration after memory reactivation reduces subsequent memory (Cai, Blundell, Han, Greene, & Powell, 2006; Maroun & Akirav, 2008; Wang, Zhao, Ghitza, Li, & Lu, 2008). For instance, stress blocked the reconsolidation of object-recognition memory in rats and this effect was reversed by the infusion of a glucocorticoid receptor antagonist into the amygdala (Maroun & Akirav, 2008). Comparable evidence from healthy humans is largely missing.

Therefore, we examined in the present experiment in humans whether the reconsolidation of autobiographical memories is influenced by stress. Autobiographical memories were reactivated by means of the autobiographical memory cueing test (Williams & Broadbent, 1986). Shortly after recalling episodes from their past, participants were exposed to stress (socially evaluated cold pressor test, SECPT) or a non-stressful control condition. The effect of stress on memory reconsolidation was assessed in a memory test 7 days after reactivation. To ensure that stress did not affect memory independent of memory reactivation, we included a group of subjects that were stressed without prior reactivation. In order to control for the effect of time on memory, we had another control

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group that was not stressed and did not reactivate experiences from their past. Based on the existing rodent data (Maroun & Akirav, 2008; Wang et al., 2008) we predicted that stress would impair memory reconsolidation.

## 2. Methods

### 2.1. Participants and design

Sixty-four healthy, non-smoking students of the Ruhr-University Bochum participated in this experiment (32 men, 32 women; age: M = 23.3 years, SEM = 0.4 years). Participants were asked to refrain from meals, drinking alcohol or caffeine, and severe physical exercise within the 2 h before the experiment. All subjects provided written informed consent for their participation in the study protocol which was approved by the ethics committee of the German Psychological Society (DGPs).

There were four experimental groups (eight men and eight women per group). Participants were either exposed to a stressor or a non-stressful control condition after they had recalled neutral and emotional experiences from their past (*react + stress* and *react + control* group, respectively). Another group of participants was exposed to the stressor without prior memory reactivation to control for the possibility that memory was influenced by the stress exposure irrespective of memory reactivation (*stress only* group). Finally, a fourth group of subjects was neither stressed nor did they reactivate autobiographical memories, i.e. they omitted experimental day 1 (*control* group). The critical memory test was given 7 days after day 1 and was basically the same in the four groups. All experiments were carried out in the afternoon between 1 pm and 6 pm.

### 2.2. Reactivation of autobiographical memories

We used a modified version of the autobiographical memory cueing test (Williams & Broadbent, 1986) to reactivate participants' autobiographical memories. Participants of the *react + stress* and *react + control* groups were presented two positive (happy, interesting), two neutral (concentrated, busy) and two negative adjectives (sad, angry) in randomized order. They were instructed to remember, in as much detail as possible, for each adjective one specific episode, including, e.g. a specific time and specific place, from their own past. In retrospect, participants recalled indeed specific events they had experienced. For example, one participant mentioned for the adjective "sad": "I was sad, when I heard of the death of the German national keeper Robert Enke last Tuesday. It was about 10 pm and I was working on my desk when my sister came to my room and told me that he was dead (...)".

To control for the age of the reactivated memories, participants were asked to remember events that were at least 24 h and at maximum 3 weeks old. There was a time limit of 4 min for each of the six adjectives. After participants had written the events down, they were asked to indicate when each event occurred and to give each memory a title (which should help to refer to the events on experimental day 2).

### 2.3. Stress protocol

About 10 min after the reactivation of the autobiographical memories, participants in the *react + stress* group were exposed to the socially evaluated cold pressor test (SECPT), a stress protocol that has been described in detail elsewhere (Schwabe, Haddad, & Schachinger, 2008). Briefly, participants were asked to immerse their right hand up to and including the wrist for 3 min into ice water (0–2 °C). During hand immersion they were recorded by a video camera and monitored by a rather cold experimenter. This procedure is known to elicit significant increases in cortisol and autonomic activity (Schwabe, Bohringer, & Wolf, 2009; Schwabe & Wolf, 2009b; Schwabe et al., 2008). Participants in the *react + control* group submerged their right hand up to and including the wrist into warm water (35–37 °C); they were neither monitored nor videotaped.

To assess the success of the stress induction by the SECPT, we measured blood pressure, salivary cortisol and subjective feeling at several time points across the experiment.

#### 2.3.1. Blood pressure

Blood pressure was measured immediately before, during and immediately after the SECPT or control condition with the Dinamap system (Critikon, Tampa, Florida); the cuff was placed at the left upper arm.

#### 2.3.2. Saliva sampling and cortisol analyses

Saliva samples were collected with the help of Salivette (Saarstedt, Germany) collection devices immediately before and immediately after the SECPT or control condition as well as 30 min after the treatment when the cortisol peak was expected (Schwabe et al., 2008). Furthermore, we took one saliva sample before the retention test on experimental day 2 to ensure that groups did not differ in their cortisol levels at test. Free cortisol concentrations were measured from saliva using an immunoassay (IBL, Hamburg).

#### 2.3.3. Subjective assessment

After the SECPT or control condition, participants rated on a scale from 0 ("not at all") to 100 ("very much") how stressful, painful and unpleasant they had experienced the previous treatment.

### 2.4. Memory test

One week after experimental day 1, subjects in the *react + stress* and *react + control* groups were presented the titles of the autobiographical events they had recalled the week before. They were asked to remember again as many details as possible of the referring event. Participants in the *stress only* and *control* groups completed the autobiographical memory cueing test as did the other two groups on day 1, except that they were instructed to recall events that were at least 1 week and at most 3 weeks old. Again, there was a time limit of 4 min for each adjective and memory title, respectively.

The autobiographical memories were assessed by two independent raters. One point was given for each remembered detail (i.e. for each person, location, time, feeling, etc. that was mentioned; e.g. the above mentioned example memory received eight points). The agreement between the two raters was very high (interrater reliability $r_{icc}$ = .93). Discrepancies were discussed until an agreement was reached. Points were first summed up for each event and then averaged for the positive, neutral and negative events. Because the *control* group omitted experimental day 1, our analyses focused on memory performance on day 2.

### 2.5. Mood assessment

To control for possible effects of mood-dependent memory (Lewis & Critchley, 2003), participants completed a multidimensional German mood scale (MDBF; Steyer, Schwenkmezger, Notz, & Eid, 1994) at the beginning of experimental days 1 and 2. This questionnaire measures three dimensions of subjective feeling ("elevated vs. depressed mood", "wakefulness vs. sleepiness", "calmness vs. restlessness") on a 5-point rating scale ranging from "not at all" (=1) to "very much" (=5).