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Acute psycho-social stress does not disrupt item-method directed forgetting, emotional stimulus content does

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ABSTRACT

It has been shown that stress affects episodic memory in general, but knowledge about stress effects on memory control processes such as directed forgetting is sparse. Whereas in previous studies item-method directed forgetting was found to be altered in post-traumatic stress disorder patients and abolished for highly arousing negative pictorial stimuli in students, no study so far has investigated the effects of experimentally induced psycho-social stress on this task or examined the role of positive picture stimuli. In the present study, 41 participants performed an item-method directed forgetting experiment while being exposed either to a psychosocial laboratory stressor, the Trier Social Stress Test (TSST), or a cognitively challenging but non-stressful control condition. Neutral and positive pictures were presented as stimuli. As predicted, salivary cortisol level as a biological marker of the human stress response increased only in the TSST group. Still, both groups showed directed forgetting. However, emotional content of the employed stimuli affected memory control: Directed forgetting was intact for neutral pictures whereas it was attenuated for positive ones. This attenuation was primarily due to selective rehearsal improving discrimination accuracy for neutral, but not positive, to-be-remembered items. Results suggest that acute experimentally induced stress does not alter item-method directed forgetting while emotional stimulus content does.

1. Introduction

In recent years, there has been a great amount of research on the effects of stress on episodic memory (for a review, see e.g. LaBar & Cabeza, 2006): Whereas memory consolidation has been found to be facilitated by acute stress (Beckner, Tucker, Delville, & Mohr, 2006), the opposite seems to hold for memory retrieval (Buchanan & Tranel, 2008). Effects are assumed to be due to the activation of two interconnected bodily systems that serve to adapt the organism to challenging environmental conditions and stressful situations: An initial sympathetic nervous system response with release of catecholamines and the hypothalamus–pituitary–adrenal (HPA) axis that kicks in several minutes later (Cohen, Kessler, & Gordon, 1997) with a release of glucocorticoids. The glucocorticoid cortisol as a marker of HPA-axis activity has been investigated thoroughly and several cortisol effects on episodic memory have been identified. However, the growing amount of research on stress effects on episodic memory in general is not mirrored in the investigation of the influence of stress on memory control processes.

Efficient memory control is needed for accurate selection of currently relevant information from the huge amount of information available in the environment and in human memory without being distracted by non-relevant material (for an overview, see Bjork, Bjork, & Anderson, 1998). This is an essential prerequisite for a focused and successful task performance. One widely studied experimental memory control paradigm is directed forgetting, where some portions of the material presented for learning are, after presentation, designated as 'to-be-remembered', while others are 'to-be-forgotten'. Directed forgetting experiments demonstrate that, in general, the explicit instruction to forget some and to memorize other stimuli is reflected in better recall of to-be-remembered stimuli compared to to-be-forgotten stimuli. This effect has been demonstrated to occur independently of social desirability or motivational demands (MacLeod, 1999). Two different basic designs exist, the list-method and the item-method. In the list-method, participants study two lists of stimuli one of which has to-be-forgotten. Here, a directed forgetting effect is found only in free recall, but not in recognition, implying that retrieval inhibition underlies list-method directed forgetting (Basden & Basden, 1996; Basden, Basden, & Gargano, 1993). By contrast, in the item method the instruction to forget or to remember follows each individual stimulus and directed forgetting effects are seen in both free recall and recognition, suggesting that effects are due to differential

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processing during encoding (Basden & Basden, 1996). Recent research has demonstrated that item-method directed forgetting depends on both selective rehearsal (Basden et al., 1993) of 'to-be-remembered' items (R-items) and on active inhibition of 'to-be-forgotten' items (F-items) induced by the 'forget' (F) cue (Hauswald, Schulz, Iordanov, & Kissler, 2010; Paz-Caballero, Menor, & Jimenez, 2004; Wylie, Foxe, & Taylor, 2008). For successful directed forgetting to occur, items need to be held in maintenance rehearsal until the processing instruction appears. Upon cue presentation, selective rehearsal of R-items and/or active inhibition of F-items, respectively, have to be initiated. These mechanisms are assumed to act on initial stimulus processing during the encoding phase, thereby affecting the way the items are stored. The thus created 'storage deficit' in item-method directed forgetting then shows up on both recall and recognition tests.

So far, no experimental studies have investigated the effect of stress on item-method directed forgetting. However, neuroscientific studies of item-method directed forgetting demonstrate specific activations of limbic and frontal regions and indicate that interactions of hippocampus, rhinal cortex and cingulate cortex with frontal and prefrontal areas give rise to the effect (Ludowig et al., 2009; Paz-Caballero et al., 2004; Wylie et al., 2008). Similar brain regions have been identified as particularly susceptible to adverse effects of stress, since the limbic system (Joëls & de Kloet, 1994) and the prefrontal cortex are particularly rich in glucocorticoid receptors (e.g., Lyons, Lopez, Yang, & Schatzberg, 2000; for an overview, see McEwen, 2007), implying the possibility of stress-induced disruption of directed forgetting.

Clinical studies have used directed forgetting paradigms to investigate memory control in stress disorder patients (McNally, Clancy, & Schacter, 2001; McNally, Metzger, Lasko, Clancy, & Pitman, 1998; Moulds & Bryant, 2002). Acute (ASD) and posttraumatic stress disorder (PTSD) patients often suffer from uncontrollably surfacing memories of their experiences and directed forgetting has been used as an experimental model to study memory control in such patients. Extant clinical studies on the effect of traumatic stress on directed forgetting provide mixed results with some studies suggesting reduced (e.g., Cottencin et al., 2006) and others enhanced (e.g., Moulds & Bryant, 2002) directed forgetting in clinical groups. Clinical data also suggest that stress effects on memory control can change over time. Moulds and Bryant (2008), in a 12-month prospective study of acute stress disorder patients and controls showed largely similar directed forgetting patterns 1 month after the patients' critical incidents, with both groups showing directed forgetting for neutral as well as trauma-related material. One year later, however, the stress group failed to exhibit directed forgetting for trauma-related material, while the controls had not changed. Studies also indicate an interaction of the material's emotional significance with stress disorder patients' item-method directed forgetting performance (e.g., Korfine & Hooley, 2000).

Alterations in item-method directed forgetting in anxiety disorders have been reported for negative (Korfine & Hooley, 2000), neutral (Cottencin et al., 2006) and notably also positive material. Wilhelm, McNally, Baer, and Florin (1996) for example report less directed forgetting for positive material in obsessive–compulsive disorder, but a follow-up study by Tolin, Hamlin, and Foa (2002) found valence per se not to contribute to impaired directed forgetting in OCD. Moulds & Bryant's (2002) data show ASD severity to negatively correlate with recognition of positive R material in a directed forgetting experiment, resulting in no directed forgetting of positive words in ASD.

Here, we investigate for the first time experimentally, if and how acutely induced stress affects directed forgetting and whether the material's emotional significance or its interaction with stress play a role (e.g., Moulds & Bryant, 2008). Previous data from our group investigating severely traumatized people in Uganda (Zwissler et al., submitted for publication) revealed an absence of directed forgetting in people with PTSD which was mediated by stimulus arousal. Directed forgetting was reduced in participants who rated the material as more arousing, participants with a PTSD diagnosis giving on average higher ratings. The impact of emotional stimuli on directed forgetting is also supported by a study of healthy volunteers from our group (Hauswald et al., 2010) where item-cued directed forgetting occured for neutral pictures, but not for highly arousing negative ones. Still, it is unclear, whether arousing positive stimuli also affect directed forgetting and whether or how emotional stimuli interact with experimental stress.

The present study wants to experimentally assess the influence of stress on item-method directed forgetting and extend knowledge on directed forgetting of emotional material by determining whether previously shown reductions in item-method directed forgetting for negative material in healthy students extend to positive valence using both positive and neutral stimuli.

Half of the participants were exposed to a standardized psychosocial stressor, which has been shown to influence memory in various situations (Jelicic, Geraerts, Merckelbach, & Guerrieri, 2004; Smeets, Jelicic, & Merckelbach, 2006), the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993). The other half was assigned to a cognitively challenging control task. Stress experience was validated via self-report questionnaires and salivary cortisol samples. In this first study of experimental stress effects on directed forgetting we use a typical paradigm and adhere to previously used parameters. Stress-induction commences shortly before, and stress experience is maintained throughout the theoretically critical encoding phase. The recognition phase follows shortly after the encoding phase, in the absence of the psychosocial stressor, but possibly still under elevated cortisol. This follows the typical item-method directed forgetting design (Lit.) and parallels the clinical analogy, since stress disorder patients suffering from chronic stress are likely to be in a similar physiological state during both phases of the experiment.

On the basis of prior research, we expected to replicate both a clear hormonal response to the experimental stressor and, at least for neutral stimuli, a solid directed forgetting effect in the control group. Going beyond these data, we investigate whether experimental stress and/or the material's emotional content (positive versus neutral) affects directed forgetting.

2. Methods

2.1. Participants

Forty-one healthy native German students (16 women) from the University of Konstanz (age range: 19–30 years, mean age = 22.24, *SE* = .40) took part in this study. They were recruited in lectures and by posters around campus. All participants reported to be free from any acute or chronic disease; moreover, according to screening with the German version of the Beck Depression Inventory (BDI; Hautzinger, Bailer, Worall, & Keller, 1994) none of them showed clinically relevant depression scores (*mean BDI score* = 4.29; *SE* = 0.57). A standardized interview asked the participants about variables known to affect the physiological stress response, such as smoking habits, or, in female participants, use of oral contraceptives. All participants were instructed via e-mail not to eat or drink high-caloric beverages, not to consume caffeine, and not to smoke for 1 h before the beginning of the experiment. All participants reported to have complied with these requirements.

Participants were randomly assigned to either the stress (n = 21; seven women) or control condition (n = 20; nine women).

The two groups did not differ in body mass index, BDI scores and smoking habits (all *p*s > .2). Thirteen women (six in the TSST group, seven in the control group) used monophasic OCs, three women (one in the control group, two in the stress group) did not use hormonal contraception. A Pearson chi-square exact test indicated no group difference in the distribution of contraceptive medication (χ^2 (1, N = 16) = .41; p = .52).

The study was approved by the local ethics committee and the participants provided written informed consent. Upon completion of the experiment, participants received course credit or 10 € as a compensation and were debriefed about the purpose of the study.

2.2. Treatment, stimuli and memory testing

In order to control for the diurnal cycle of cortisol, experimental sessions were all started in the afternoon either at 1:00 p.m., 2:30 p.m., or 4:00 p.m, with starting times balanced between groups. The participants were tested individually by an experimenter who conducted the interview and explained the procedure. In the stress group, the experimenter was supported by two confederates who formed the 'stress induction committee' (see below). The sequence of experimental events is depicted in Fig. 1.

2.2.1. Treatment: stress induction versus control task

2.2.1.1. Stress induction – Trier Social Stress Test (TSST). The Trier Social Stress Test (TSST; Kirschbaum et al., 1993) was used as an experimental stressor. It has been shown to be effective in inducing stress and activating the HPA-axis (Kirschbaum et al., 1993). The TSST consists of two tasks (free speech and mental arithmetic) participants are asked to perform in front of a two-person selection panel whose members are confederates of the experimenter. They are instructed to withhold facial and verbal feedback and to communicate with the participant in a neutral manner. Participants are asked to take over the role of a job applicant and to deliver a speech in which s/he has to convince the panel that s/he is the perfect applicant for a job. One of the panel members informs the participant about the task. The participant has 3 min to prepare the talk while sitting in front of the panel and another 5 min to deliver the speech. Then a mental arithmetic task follows. Participants are asked to serially subtract 13 starting from 1687 as quickly and accurately as possible for another 5 min. If the participant makes an error, the panel chairperson says "error", and the participant is asked to restart at 1687. During both the speech and the subtraction task, participants stand in front of the committee, speak into a microphone and are videotaped.

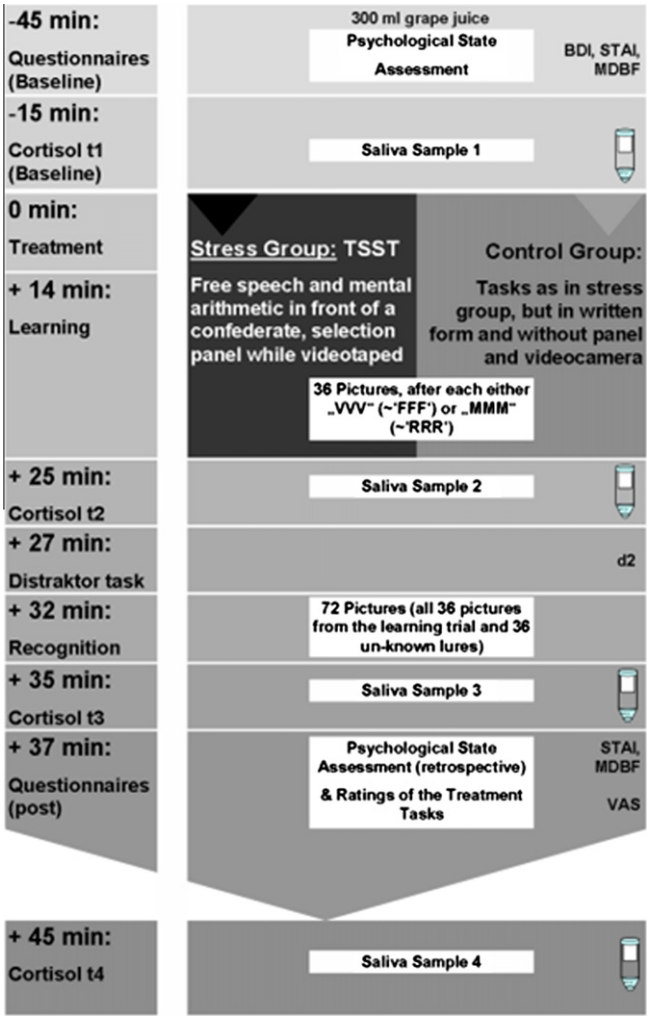

Fig. 1. Typical experimental procedure.

2.2.1.2. Control task. The control task contained the same tasks (verbal and numeric) as the TSST to equate cognitive load. However, the stressful social and self-relevant components were omitted. Instead of the free speech in the TSST, participants were asked to write a fictitious job application for a friend. As in the TSST group, the control group had 3 min for preparation and an additional 5 min to write the application letter. In the following arithmetic task, the participants were also asked to serially subtract 13 starting with 1687 for 5 min and to write the results into a booklet that contained correct control figures on every fifth page enabling them to detect their own arithmetic errors and correct them by paging back.

2.2.2. Stimuli

In a pre-test, 75 pairs of similar complex photographs were rated on the dimensions arousal and valence, using a 9-point scale, by 12 participants who did not take part in the actual experiment. Eighteen picture pairs that had been clearly rated as neutral and 18 pairs rated as positive were chosen for memory testing. The neutral pairs were rated medium in valence (M = 4.51, SE = .14) and arousal (M = 3.37, SE = .12) and the ones selected as positive were rated as significantly more positive (M = 7.22, SE = .08, $t(11)$ = 13.87, p < .001) and more arousing (M = 4.77, SE = .27, $t(11)$ = 5.56, p < .001). The pictures showed people, landscapes, sports activities, animals, or social scenes (see Fig. 1a and b for examples). Since the panel members were present during the learning phase, we were careful not to induce other psychological states besides stress (e.g. embarrassment and shame) and avoided pictures of highly arousing erotic scenes that are commonly used. Therefore, the difference in mean arousal ratings between neutral and positive pictures is smaller than in some other studies in the literature.

One picture from each pair was assigned to each of the two sets (set A and set B). Picture-set assignment was counterbalanced. During learning, all set A – pictures were presented in random order. In the recognition phase, all pictures from both sets were presented randomly, set B pictures serving as related lures. Picture sets A and B did not differ with regard to valence ($t(22)$ = .10; p = .92) and arousal ($t(22)$ = .51; p = .62). Examples for neutral and pleasant stimulus pairs are shown in Fig. 2.

2.3. Memory Testing: directed forgetting

2.3.1. Learning phase

The learning phase took place directly after the serial subtraction task in both groups. In the experimental group, the committee stayed in the room during this phase to maintain the social stress

Fig. 2a. Illustration of the neutral picture sets. Examples of target-distractor pairs.

Fig. 2b. Illustration of the positive picture sets. Examples of target-distractor pairs.

experience. The panel chairperson instructed the participant. In the control group, only the experimenter was in the room. Participants were explained that they would be presented photographs which after presentation would be labelled individually as relevant (i.e. 'remember it') or as irrelevant (i.e. 'forget it'). Then, the participants were shown 36 photographs for 2 s each on a laptop computer placed on a table in front of them. After each picture, either the 'forget' instruction symbolized by 'VVV' ('vergessen ~ forget') or the 'remember' instruction signalled by 'MMM' ('merken ~ remember') appeared for 2 s. After another 1 s, during which a fixation cross was presented on the screen, the next picture was presented. After this learning phase, there was a break of 10 min during which in the stress group the panel left the room and the experimenter took over. In both groups, a saliva sample was taken by the experimenter and an attention test ('d2') was carried out as a distracter task.

2.3.2. Recognition phase

A two-alternative recognition test (old, new), consisting of a random sequence of the 36 old and 36 similar new pictures (paired lures), was administered. Each picture was shown for 300 ms and participants were asked to decide as quickly as possible, whether they had seen this picture before. Although fast responses were encouraged, there was no pre-defined time limit for responses. After the response was given, a fixation cross was presented for 700 ms before the next picture appeared. During this phase of the experiment, only the experimenter was present.

All experimental material was presented on a laptop computer (Dell Latitude D830) using Presentation Software (Neurobehavioral Systems Inc., Albany, NY).

The sequence of experimental events for the two groups is shown in Fig. 1.

2.4. Treatment validation

2.4.1. Saliva cortisol sampling and psychological assessment

Saliva samples for cortisol determination were obtained with commercially available collection devices (Salivette, Sarstedt, Nümbrecht, Germany). For individual cortisol baseline measurements prior to the study phase of the directed forgetting experiment, participants had to rest for approximately 30 min. They were still naïve regarding group assignment. As suggested by Kudielka, Hellhammer, Kirschbaum, Harmon-Jones, and Winkielman (2007), participants of both groups were asked to drink 300 ml of grape juice to standardize blood glucose levels 15 min prior to the salivary baseline sampling before the experiment. To assess stress-induced changes in salivary cortisol, three further samples were taken at 25, 35 and 45 min after the beginning of the TSST and control task respectively.

Relevant clinical variables and psychological stress responses were assessed pre-experimentally with different questionnaires. Participants were asked to fill in a German version of the Beck Depression Inventory (BDI; Hautzinger et al., 1994), the German version of the State-Trait Anxiety Invetory (STAI; Laux, Glanzmann, Schaffner, & Spielberger, 1981), and a German mood and alertness scale, the 'Mehrdimensionale Befindlichkeitsfragebogen' (MDBF; Steyer, Schwenkmezger, Notz, & Eid, 1994) with its three subscales "mood", "alertness", and "calmness". At the very end of the experiment, just after the fourth and last saliva sampling, the STAI, and the MDBF were filled in once again. Moreover, seven visual analogue scales were administered in order to be able to compare

the participants' appraisal of their task between the two groups. Participants indicated their personal involvement, the task's novelty, difficulty, stressfulness, and unpredictability, and their anticipation of negative consequences by marking the appropriate point on a continuum ranging from "not at all" to "extremely".

2.4.2. Saliva cortisol analysis

Saliva collection devices were centrifuged (1000*g*, 10 min, 4 °C) and the recovered saliva was stored at −20 °C until assayed. Salivary cortisol concentrations were measured with a commercial enzyme-linked immunosorbent assay (Cortisol ELISA, IBL International, Hamburg, Germany) according to the manufacturer's instructions. Intra- and inter-assay variances were 5.6% and 8.8%, respectively.

2.5. Statistical analyses

All statistical calculations were performed with Statistica 6.1© (StatSoft, Inc. 2003, www.statsoft.com). The behavioural data were analyzed using repeated-measures ANOVAs with the within-factors cue (Forget, Remember), and valence (Neutral, Positive), and the between-factor treatment (Control, TSST). Post hoc comparisons were calculated using Tukey's HSD test. Pearson product-moment correlation analyses between memory measures and cortisol levels were performed to assess potential cortisol effects on recognition memory. An alpha level of .05 was used for all calculations.

3. Results

3.1. Manipulation check: stress induction versus control task

3.1.1. Cortisol levels

As expected, participants in the stress group showed a significant increase in free salivary cortisol after the TSST. A repeated-measures ANOVA with the two factors treatment (stress vs. control) and measurement time (baseline, +25, +35, +45 after TSST-onset) yielded a significant treatment by time interaction (F (3, 117) = 15.68, $p < .001$). Targeted comparisons showed comparable baseline levels between groups ($t(39) = .06$, $p = .96$) as well as significantly different cortisol levels at time +25 ($t(39) = 3.81$, $p < .001$), time +35 ($t(39) = 3.41$, $p < .01$) and at time +45 ($t(39) = 3.98$, $p < .001$). Moreover, a significant increase within the TSST group from baseline to +25 ($t(20) = 5.04$, $p < .001$) was found. Fig. 3 depicts the time course of the cortisol response in both groups.

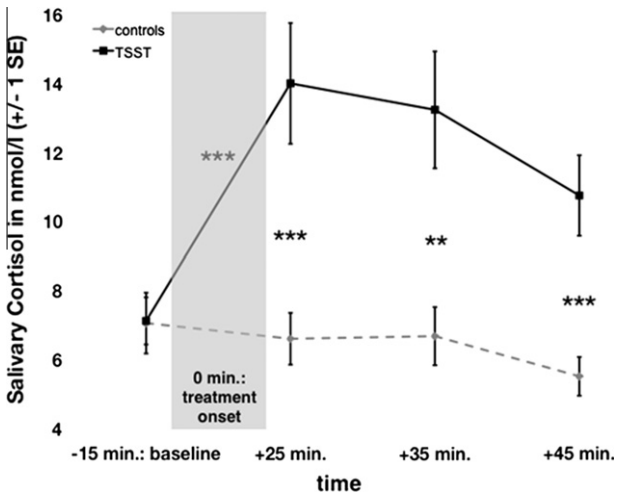

Fig. 3. Course of the cortisol response (in nmol/l ±SE) in stress and control group. Asterisks indicate significance (**$p < .01$, ***$p < .001$).

3.1.2. Psychological assessment

3.1.2.1. State and trait anxiety: State-Trait Anxiety Inventory. Repeated-measures ANOVA with the factors measurement time (before and after the treatment) and treatment (stress vs. control) revealed that there were neither treatment by time interactions with regards to either state (F (1, 39) = 2.64; $p = .11$) or trait (F (1, 39) = .32; $p = .57$) anxiety nor any significant main effects.

3.1.2.2. Mood and alertness: 'Mehrdimensionaler Befindlichkeitsfragebogen' (MDBF). The same repeated measurement analysis also showed no effects on any of the three MDBF subscales mood (F (1, 39) = .01; $p = .93$), alertness (F (1, 39) = .00; $p = .96$), and tranquillity (F (1, 39) = .10; $p = .75$).

3.1.2.3. Participants' appraisal of the experimental tasks: Visual Analogue Scales (VAS). The analysis of the seven VAS revealed that participants rated the TSST as significantly higher in task difficulty ($t(39) = 4.10$; $p < .001$), stressfulness ($t(39) = 4.76$; $p < .001$), anticipation of negative consequences ($t(39) = 2.42$; $p < .05$), personal challenge ($t(39) = 2.69$; $p < .05$) and, marginally, in task novelty ($t(39) = 1.96$; $p = .06$). No clear difference between the groups was found in unpredictability ($t(39) = 1.31$; $p = .20$), and personal involvement ($t(39) = .55$; $p = .59$).

3.2. Memory performance

3.2.1. Hits and false alarms

Calculations are based on proportions of pictures participants categorized as "old" in the recognition test. The response rates for pictures that were correctly identified as "old" (i.e. hits) and not presented lures that were erroneously labelled as "old" (i.e. false alarms) are shown in table 1, separately for neutral and positive pictures.

With regard to hits, a two-(valence: Positive, Neutral) by two-(cue: Remember, Forget) by two-(treatment: Control, TSST) repeated-measures ANOVA yielded a significant cue main effect (F (1, 39) = 17.43; $p < .001$) with more hits for R pictures than for F pictures, which is indicative of directed forgetting. Moreover, a significant valence main effect (F (1, 39) = 4.53; $p < .05$) with more hits for neutral pictures than for positive ones was found. However, neither a significant main effect of treatment (F (1, 39) = .70; $p = .41$), significant two-way interactions of valence and treatment (F (1, 39) = .25; $p = .62$), cue and treatment (F (1, 39) = .44; $p = .51$), valence and cue (F (1, 39) = .19; $p = .67$) nor a significant three-way interaction (F (1, 39) = 1.55; $p = .22$) were found.

Regarding false alarms in a two-(valence: Positive, Neutral) by two-(cue: Remember, Forget) by two-(treatment: Controls, TSST) repeated-measures ANOVA only the interaction of valence and cue reached significance (F (1, 39) = 10.43; $p < .01$): More false alarms were made to positive R lures than to neutral R lures ($p < .01$). That is, for the positive R items' paired distracters false alarms were higher than for the neutral R items' paired distracters. Moreover, for neutral pictures, false alarms were reduced for R lures compared to F lures ($p < .01$). This was not the case for positive pictures. Other than this, marginally significant main effects of cue (F (1, 39) = 3.58; $p = .07$; more false alarms for F lures compared to R lures) and treatment (F (1, 39) = 3.77; $p = .06$; more false alarms made by the TSST group compared to controls) were found. Neither significant main effects of valence (F (1, 39) = 2.21; $p = .15$), nor significant interactions of valence and treatment (F (1, 39) = .33; $p = .57$), cue and treatment (F (1, 39) = .48; $p = .49$) were found. The three-way interaction was far from significant (F (1, 39) = .003; $p = .96$).

Table 1
Response rates of positive and neutral stimuli in the stress group, the control group and overall, separately for hits and false alarms.

	Hits				False alarms			
	Neutral pictures		Positive pictures		Neutral pictures		Positive pictures	
	"Remember" (SE)	"Forget" (SE)	"Remember" (SE)	"Forget" (SE)	"Remember"-lures (SE)	"Forget"-lures (SE)	"Remember"-lures (SE)	"Forget"-lures (SE)
Controls (n = 20)	0.87 (0.03)	0.76 (0.04)	0.80 (0.03)	0.71 (0.04)	0.16 (0.03)	0.25 (0.04)	0.26 (0.03)	0.23 (0.03)
TSST (n = 21)	0.85 (0.03)	0.81 (0.03)	0.85 (0.03)	0.74 (0.05)	0.22 (0.04)	0.35 (0.03)	0.30 (0.03)	0.30 (0.04)
Overall (n = 41)	0.86 (0.02)	0.78 (0.03)	0.83 (0.02)	0.73 (0.03)	0.19 (0.02)	0.30 (0.03)	0.28 (0.03)	0.27 (0.03)

3.2.2. Discrimination accuracy and recognition bias

To take into account hits and false alarms simultaneously and to distinguish discrimination accuracy from response bias in the data, discrimination accuracy (P_r = Hits – false alarms) and recognition bias (B_r = false alarms/(1 – P_r)) were analyzed according to Snodgrass & Corwin's (1988) two-high-threshold model. A two-(valence: neutral, positive) by two-(cue: remember, forget) by two-(treatment: TSST, controls) repeated-measures ANOVA of P_r yielded a cue main effect (F (1, 39) = 18.72; p < .001) with more R pictures than F pictures being recognized, that is directed forgetting was found. Moreover, a valence main effect (F (1, 39) = 7.83; p < .01) with a better discrimination accuracy for neutral pictures and a valence × cue interaction with reduced directed forgetting of positive stimuli were found (F (1, 39) = 5.91; p < .05). There were neither significant treatment × valence (F (1, 39) = .68, p = .41), treatment × cue (F (1, 39) = .01; p = .92) or treatment × cue × valence interactions (F (1, 39) = 1.12; p = .30) nor a treatment main effect (F (1, 39) = .49, p = .49). Targeted post hoc comparisons of P_r (R) and P_r (F) revealed significant directed forgetting of neutral pictures both in controls (p < .01) and stressed participants (p < .01) but no directed forgetting of positive pictures in controls (p = .93) or the TSST group (p = .25). With regard to B_r no significant effects appeared. The effect of experimental stress and stimulus valence on directed forgetting as reflected in recognition accuracy is shown in Fig. 4.

3.2.3. Correlation analyses

No correlations between cortisol levels and the directed forgetting effect itself were found. However, there were significant negative correlations between absolute cortisol levels and P_r for positive F pictures (−15 min: r = −.44, 25 min: r = −.47, 35 min: r = −.50, 45 min: r = −.43; all p's < .05) and also between cortisol and P_r for neutral F pictures (−15 min: r = −.41, 25 min: r = −.38, 35 min: r = −.37, 45 min: r = −.33; all p's < .12), but the latter were not consistently significant. There was no such pattern observed for the P_r for R pictures, nor were there any other significant or trend-level correlations.

4. Discussion

This study explored whether experimentally induced stress affects directed forgetting of neutral or positively arousing complex pictures. The TSST once more proved to be an effective stressor in terms of HPA-axis activation and it was also perceived as more stressful, challenging, more likely associated with negative consequences and more difficult than the control task. Yet, directed forgetting was found both in participants having undergone the TSST and in participants in the control condition. The emotional content of the stimuli, on the other hand affected directed forgetting: It was intact for neutral pictures, but reduced for positive ones. Reduction for positive stimuli was primarily due to differential false alarm rates: For neutral stimuli, false alarms were reduced for distractors related to 'remember' compared to 'forget' items whereas for positive stimuli, false alarms were higher for distractors related to 'remember' items. That is, whereas the 'remember' instruction increased recognition accuracy for neutral pictures, it failed to do so for positive pictures. Such a higher false alarm rate in response to positive R stimuli is in line with findings of emotion heightening the sense of remembering, but not necessarily memory accuracy (Talarico & Rubin, 2003).

In tendency, elevated false alarm rates were found in the stress group in general, which corresponds with previous results of reduced memory accuracy under stress (Payne, Nadel, Allen, Thomas, & Jacobs, 2002). By contrast, false alarm rate was somewhat reduced for 'remember' items. This is compatible with selective rehearsal of these items resulting in more elaborated and accurate memory representations, but, as indicated above, this was mainly true neutral items. Overall, results suggest that acute stress, per se, does not hamper item-method directed forgetting. However, emotional stimuli modulate the effect.

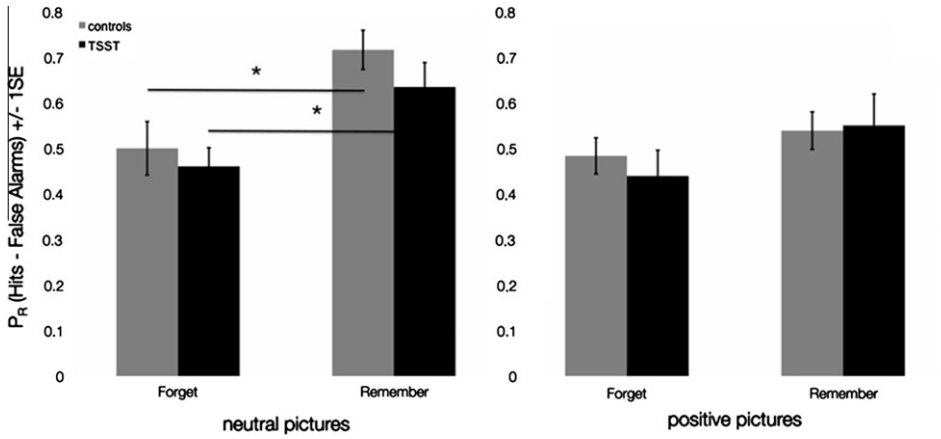

Fig. 4. Discrimination accuracy (P_r) of F and R pictures in stress and control group, separately for positive and neutral stimuli. Asterisks indicate significance ($^*p$ < .05).

Clinical and neuroimaging data had suggested that stress may interfere with directed forgetting, but in the present study no significant effect of experimental stress on directed forgetting was found. There are different possible explanations of why experimental stress did not affect directed forgetting in this investigation: Perhaps, only chronic or traumatic stress with all its long-lasting physical consequences such as chronically increased amygdala activity, decreased hippocampal volume (Hull, 2002), and less activation in medial frontal cortex (Lanius et al., 2001; Rauch, Shin, & Phelps, 2006) reduces memory control. Indeed, Cottencin et al. (2006) report a general lack of directed forgetting in PTSD patients, attributed to their reduced inhibitory capacities. Moreover, there is clinical evidence for a change in the effect of stress on directed forgetting over time. Moulds and Bryant (2008) in their prospective study of acute stress disorder, found longitudinal changes in patients' directed forgetting patterns suggesting that directed forgetting is primarily altered by long-term stress effects. One month after a highly stressful incident, acute stress disorder patients showed normal directed forgetting, whereas 12 months after the incidents they showed reduced directed forgetting.

Limbic and frontal regions (e.g., hippocampus, cingulate cortices, in interaction with frontal and prefrontal areas) have been identified to play a role in item-method directed forgetting (Paz-Caballero et al., 2004; Wylie et al., 2008), but metabolic activity in some of these regions, such as hippocampus, amygdala and cingulate cortices has been found to be reduced by experimental stress in particular in participants with a cortisol increase in response to an experimental stressor (Pruessner et al., 2008). In the present study all but three participants showed a sizeable increase in cortisol levels in response to the stressor, yet no effect on directed forgetting was found, suggesting that acute experimental stress at least at the presently induced intensities may not affect directed forgetting. Joëls (2006) postulates an inversely U-shaped relationship between corticosteroid levels and brain function, giving rise to the possibility that the present stress induction was not intense enough to affect memory. Still, the TSST has been shown to affect various memory processes (for an overview, see Kuhlmann, Piel, & Wolf, 2005) and in particular a different memory control process, retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994; Griffin, Resick, & Mechanic, 1997), has been eliminated by the presently used experimental procedure (Koessler, Engler, Riether, & Kissler, 2009).

However, scenarios exist under which effects of stress induction and cortisol secretion on different cognitive sub-processes and temporal phases of the directed forgetting experiment may counteract each other, resulting in a zero net-effect of stress on the present behavioural measures. Selective rehearsal and superior encoding of R items as well as active inhibition of F-items have been implicated in item-wise directed forgetting. Stress may have interfered with the active inhibition of F-items but at the same time strengthened the selective encoding of R-items, creating a net-effect of intact directed forgetting, but not necessarily due to an absence of stress-related memory effects. Combining stress induction with on-line measures of brain activity during directed forgetting would allow for a separate analysis of brain activities related to the forget and remember instructions and their modulation by stress, helping to examine this possibility.

Perhaps surprisingly, at present, no main effect of stress on memory performance was found.

There is the possibility that, although encoding could have been enhanced in the present sample, this advantage may have been eliminated by continuing HPA-axis activation during recognition. Even 45 min after stress onset (with the recognition task starting at about 32 min after stress onset), the TSST group still showed significantly higher salivary cortisol concentration than the control group. Different groups have reported negative consequences of cortisol on recognition (Domes, Heinrichs, Rimmele, Reichwald, & Hautzinger, 2004; Tops et al., 2003). Most likely, this would have affected 'R' and 'F' items in the same way, since the directed forgetting effect was not altered and theoretically, in the item method, the directed forgetting effect is thought to be due to differential processing of R and F stimuli in the encoding phase (Gottlob, Golding, & Hauselt, 2006). Therefore major stress effects should have occurred during the encoding phase. Also, stress induction commenced before and lasted throughout the encoding phase, such that major psychological stressor characteristics as well as the stressor itself with its respective context were absent during retrieval.

However, as the 'memory active' cortisol response, was still visible during retrieval, there is the possibility of on-going effects due to cortisol secretion although not necessarily due to the full psycho-social stress response. Differential effects of R and F instructions during recognition might occur if the effect of cortisol-induced retrieval-impairment differs between strong (R-cue associated) and weak (F-cue associated) memories. The correlations between cortisol levels and recognition performance indeed support the idea of cortisol affecting R and F stimuli differently since they only appear for recognition of F-items. Moreover, since they are negative (i.e., as cortisol levels increase discrimination accuracy decreases), they also suggest indeed retrieval processes to have been affected (following the logic of cortisol improving encoding but impairing retrieval). Although to the best of our knowledge so far no corroborating empirical evidence beyond these rather preliminary data exists, this possibility clearly merits attention.

Studies in clinical populations as well as in students suggested effects of emotional material on item-method directed forgetting, and this was presently confirmed for positive stimuli. Disorder-related stimuli have been found resistant to directed forgetting in several psychiatric populations (Elzinga, de Beurs, Sergeant, Van Dyck, & Phaf, 2000; Korfine & Hooley, 2000). A previous study from our own group (Zwissler et al., submitted manuscript) found item-cued directed forgetting of complex photographs to be reduced in Ugandan civil war victims suffering from PTSD. Notably, across both participants with and without PTSD, the directed forgetting effect was inversely correlated with arousal ratings for the stimuli, suggesting that a stimulus' subjective emotional significance affects directed forgetting. Other work from our group (Hauswald et al., 2010) showed a lack of directed forgetting for highly arousing negative pictorial stimuli already in healthy students. Further clinical data indicate that not only for negative, but also for positive material item-method directed forgetting differs between patients suffering from psychiatric disorders and healthy individuals. Wilhelm et al. (1996) for example report more reduction in directed forgetting for positive and negative compared to neutral words in obsessive–compulsive disorder (OCD) than in healthy individuals. These data indicate, that alterations in directed forgetting are not restricted to negative stimuli and may be driven by more general constructs such as arousal or self-relevance.

In the present study, whereas there was clear directed forgetting of neutral pictures both regarding hit rates and regarding discrimination accuracy, positive ones turned out to be more resistant to explicit forgetting instructions. An apparent directed forgetting effect for hit rates disappeared when false alarms were taken into account, eliminating directed forgetting on discrimination accuracy for positive pictures. Whereas the remember instruction reduced false alarms for neutral pictures, this was not the case for positive ones. For the distractors paired with positive 'to-be-remembered' items, false alarms were significantly higher than for the neutral pictures' distractors. Effectively, for neutral pictures the remember instruction improved discrimination whereas it did not for positive pictures. Therefore, calculating the directed forgetting effect for discrimination accuracy by subtracting false alarms

from hits following Snodgrass and Corwin (1988) considerably reduced the effect for positive pictures. Previous research has shown that for emotional compared to neutral scenes, memory relies more on central elements than on peripheral detail (Christianson & Loftus, 1991; Christianson, Loftus, Hoffman, & Loftus, 1991). Thus, the remember cue might have been less efficient in improving discrimination accuracy for positive than for neutral items as in the present study very similar target–distractor pairs have been used to avoid ceiling effects (see for example Figs. 2a and b). Since recognition memory in healthy young adults is remarkably good and in order to not extend the duration of the stress plus learning phase too much, we chose to avoid ceiling effects by making the task relatively difficult and to select very similar picture pairs. Moreover, using thematically dissimilar target–distractor pairs could have created an in-homogenous stimulus set, introducing response biases on some of the target–distractor pairs, but not on others, which we wanted to avoid. Therefore target–distractor pairs differed only in peripheral details. This led to more hits for neutral pictures than for positive ones in the present study, ultimately resulting in better discrimination accuracy of neutral items. Again, the higher hit rate for neutral stimuli may be due to positive picture pairs having been subjectively more difficult to distinguish than neutral ones if in the positive pictures attention was more focused on central elements as suggested by prior research (Burke, Heuer, & Reisberg, 1992). A design similar to the present one has been used by Hauswald and Kissler (2008), Hauswald et al. (2010), and Nowicka, Marchewka, Jednoróg, Tacikowski, and Brechmann (2010). The latter two studies also report an ostensible memory advantage for negative stimuli. However, when false alarms are taken into account, this mnemonic advantage disappears, since false alarms are more frequent for emotional than the neutral pictures. This may be due to the fact that emotional arousal increases gist-based decisions, which contribute to the ostensible memory advantage for emotional material. Burke et al. (1992) as well as others (Jurica & Shimamura, 1999; Kensinger, Piguet, Krendl, & Corkin, 2005; Safer, Christianson, Autry, & Oesterlund, 1998) have demonstrated that emotion impairs memory for peripheral details. Since targets and distracters did not differ much in overall gist but only in peripheral detail, this may have led to the present pattern of results, if emotion-induced attentional focusing narrowed processing to the central details, perhaps at the expense of details that would have been critical for the subsequent test. In general, emotion may increase the 'feeling of remembering' more than actual memory accuracy (Talarico & Rubin, 2003) and a recent large study (Aupee, 2007) confirms that emotional content impairs rather than improves discrimination accuracy for pictures.

Since for design reasons the positive pictures, while significantly more arousing than the neutral ones, were not overly arousing, the reduction in directed forgetting may have been less pronounced than in our previous study (Hauswald et al., 2010), where emotional content abolished directed forgetting on both hit rates and discrimination accuracy. Still, the present and previous studies, together, suggest that arousal, rather than valence, may affect item-method directed forgetting. Both positive and negative stimuli have the potential to induce arousal in experimental participants and thereby may make them overly accessible and literally uncontrollable. Although pending further research, the above discussed effects of emotional content on memory accuracy may likewise be due to stimulus arousal, rather than valence as indicated by a recent systematic study of arousal and valence effects on memory accuracy (Corson & Verrier, 2007). To conclusively settle the issue, the relative impacts of arousal and valence on item-method directed forgetting should be further examined parametrically, using stimuli that span a wider range of arousal and valence. Post-experimentally collected stimulus ratings could then be co-varied with the directed forgetting effect.

In sum, results indicate that emotional stimulus content is more powerful than an individual's psycho-physiological state in affecting directed forgetting. However, null findings can never be regarded as entirely conclusive, especially since this study used a typical directed forgetting paradigm and adhered to previously used parameters, such that encoding and recall phases were administered in close temporal proximity, resulting in elevated cortisol levels during recognition. Since theoretically encoding was considered the critical phase and since previously investigated stress disorder patients suffering from chronic stress are likely to be in a similar physiological state during both phases of the experiment, this appeared as a sensible first step. However, future studies should investigate differential effects on encoding or retrieval in this paradigm with delayed testing following stress at encoding or stress induction shortly preceding retrieval but considerably delayed after encoding. Further combinations with neuroimaging methods would allow measurement of stress effects on different sub-processes of directed forgetting during encoding and recognition. Regarding emotional modulations, this study, in synopsis with other previous ones, suggests that arousal, may drive alterations of directed forgetting. This should be further corroborated in parametric studies that vary both dimensions across a wider span than presently done.

The present investigation indicates that item-method directed forgetting is not affected by a standard experimental stressor administered before and extending into the encoding phase, at least when cortisol levels are still elevated during recognition. However, data indicate that the efficacy of this memory control mechanism depends on the emotional content of the stimuli applied. The classic response pattern was obtained for neutral pictures but not for pleasant ones. This, together with other studies, suggests that item-method directed forgetting is primarily modulated by stimulus content. Whether experimental stress can affect directed forgetting with different stressor timing or at other encoding-retrieval intervals than presently used, is open to future research.

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