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Emotional Modulation of the Attentional Blink: Is There an Effect of Stress?

Lars Schwabe and Oliver T. Wolf
Ruhr University Bochum

Individuals are often unable to identify the second target (T2) of two when it is presented within 500 ms after the first target (T1). This "attentional blink" (AB) is attenuated by an emotionally arousing T2. Stress is known to affect cognitive performance, in particular for emotional material. In the present study, we asked whether (a) an emotional T2 reduces the AB when preceded by an emotional T1 and (b) the emotional modulation of the AB is affected by stress. Participants were presented neutral and aversive words as T1 and T2 in rapid serial visual presentation after they were exposed to stress (socially evaluated cold pressor test) or a control condition in a crossover manner. Our results indicate that an aversive T1 extends the AB. Aversive T2 attenuated the AB in the presence of a neutral, but not an aversive, T1. Stress-enhanced T2 detection and high cortisol responses to stress reduced the AB. However, neither stress nor cortisol interacted with the emotionality of the target words. In summary, these findings point to a strong impact of emotional factors on early perceptual experiences.

Keywords: attention, attentional blink, emotion, stress, cortisol

Our cognitive system has limited processing capacities. The limitations of cognitive processing can be studied, for example, with rapid serial visual presentation (RSVP). Typically, individuals have problems in detecting the second of two consecutive target stimuli (T1 and T2 for first and second target stimulus, respectively) when T2 is presented very soon after T1, such as with an interval of less than 500 ms (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Shapiro, Arnell, & Raymond, 1997). It has been proposed that this transient deficit in the detection of T2, referred to as an *attentional blink* (AB), is due to the short-term consolidation of the T1, which makes attentional resources temporarily unavailable for allocation to T2 (Chun & Potter, 1995; Jolicouer, 1999).

Recent evidence indicates that the AB can be reduced when emotionally arousing stimuli are presented as T2 (Anderson & Phelps, 2001; Keil & Ihssen, 2004). This might suggest a lower threshold for emotional stimuli that frees them from the attentional limitation underlying the AB or, alternatively, that emotionally arousing material may attract more attentional resources than neutral material (Anderson, 2005). It is interesting that a recent study provided the first evidence that the AB is modulated not only by the emotionality of the T2 but also by the emotionality of the T1 (Mathewson, Arnell, & Mansfield, 2008; see also Smith, Most, Newsome, & Zald, 2006). Similar to emotional "to-be-ignored" distractors in the RSVP stream (Arnell, Killman, & Fijavz, 2007), emotionally arousing T1s caused a significant increase in the AB compared with neutral T1s, which was interpreted as extended processing of emotional T1s. In this study, however, only neutral items were presented as T2s. Whether an emotionally arousing T2 is capable of reducing the AB in the presence of an attention-attracting emotional T1 is not known. Given that our attentional capacities are limited and the processing of the T1 is the main cause for the AB, it is predicted that the extended processing of emotionally arousing T1 inhibits the AB attenuation by an emotionally arousing T2.

In addition to the emotionality of the stimulus material, cognitive performance can be influenced by the emotional state of the individual (Christianson, 1992). There is plenty of evidence for altered cognitive functions when individuals are stressed (Joels, Pu, Wiegert, Oitzl, & Krugers, 2006; Wolf, 2008). Hormones released during stressful experiences, such as noradrenaline and cortisol, influence brain structures relevant for attention, learning, and memory (Joels et al., 2006). The influence of stress (hormones) on learning and memory is well documented and depends on the timing of the stress exposure. Stress within the context of the learning experience enhances memory, whereas stress outside of the learning context impairs memory (Joels et al., 2006). It is interesting that these effects are most pronounced for emotional material (Kuhlmann, Piel, & Wolf, 2005; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008). Less is known about stress effects on attention processes. Only relatively few studies examined the impact of stress on attention. These yielded inconsistent findings, with some studies showing enhancing effects of stress (hormones) (Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007; Roelofs, Bakvis, Hermans, van Pelt, & van Honk,

Lars Schwabe and Oliver T. Wolf, Department of Cognitive Psychology, Ruhr University Bochum.

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Correspondence concerning this article should be addressed to Lars Schwabe, Department of Cognitive Psychology, Ruhr University Bochum, Universitaetsstrasse 150, 44789 Bochum, Germany. E-mail: lars.schwabe@rub.de

2007), whereas others found no effect of stress on attention (Kuhlmann et al., 2005; Lupien, Lecours, Lussier, Schwartz, Nair, & Meaney, 1994). To our knowledge, the effect of stress on performance in a RSVP task (i.e., on the AB) has not been tested. On the basis of previous findings showing that stress before learning may enhance subsequent recall (Nater et al., 2007; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008), we expected an enhancing effect of stress on attention. As stress effects on memory are most pronounced for emotional material, it is tempting to speculate that stress might enhance the attention for emotional T2 (and possibly emotional T1) in particular and thus boost the emotional modulation of the AB.

In the present study, we aimed to answer three questions: (a) Can an emotionally arousing T2 still reduce the AB when the T1 is also emotionally arousing? (b) Does stress enhance T2 detection in a RSVP task? (c) Does stress amplify the emotional modulation of the AB? To this end, participants were exposed to a stress or a control condition in a crossover manner before they performed a RSVP task in which neutral and emotionally arousing (aversive) words were presented as T1 and T2.

Method

Participants and Design

Thirty-six healthy, nonsmoking men recruited at Ruhr University Bochum in Bochum, Germany, participated in this experiment (age: $M = 24.1$ years, $SEM = 0.5$ years). They had normal or corrected-to-normal vision and were paid €20 for participation. Participation was restricted to men to avoid sex hormone effects on stress responses (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). All participants provided written informed consent, and the study protocol was approved by the ethics committee of the German Psychological Society.

We used a within-participant design. All participants completed two experimental sessions; they performed the AB task once after a stress exposure and once after a nonarousing control condition. Between the two sessions, there was a 1-week washout period. Two parallel versions of the AB task were available, which differed solely in the presented words. The order of the stress and control conditions, as well as the AB task versions, was counterbalanced across participants.

Stress and control conditions. In the stress condition, participants were exposed to the socially evaluated cold pressor test (SECPT) as described in detail elsewhere (Schwabe, Haddad, & Schachinger, 2008). Briefly, participants immersed their right hands up to and including the wrist for up to 3 min (or until they could no longer tolerate it) in ice water (0–2 °C). During hand immersion, they were monitored by an unfamiliar person and videotaped. In the control condition, participants immersed their right hands for 3 min in warm water (35–37 °C); they were neither monitored nor videotaped. To assess the success of the stress induction by the SECPT, participants rated immediately after the treatment how stressful, unpleasant, and painful the hand immersion was. Moreover, blood pressure was measured and saliva samples were taken at several time points across the experiment. For saliva collection, Salivette (Sarstedt, Germany) collection devices were used. The biologically active fraction of the stress hormone cortisol was analyzed from saliva by an immunoassay (IBL, Hamburg, Germany).

Stimuli. Participants were presented neutral (e.g., time, wood, line) and aversive (e.g., bitch, bastard, ass) German nouns as T1 and T2 in the RSVP procedure. T1 and T2 were matched for word length. Furthermore, the neutral and aversive words were rated by 40 students (22 women, 18 men; mean age = 25.7 years, $SEM = 1.2$ years) who did not participate in the present experiment with respect to their familiarity. These ratings revealed that both neutral and aversive words were highly familiar (for both word types, average familiarity >95%). Distractor words were neutral German nouns that were significantly longer than the target words (12.0 vs. 5.5 letters) to ensure that the targets were masked by them. At the end of the second experimental session, participants rated the arousal and the valence of the presented words. In retrospect, these ratings verified that aversive words were experienced as significantly more negative and significantly more arousing than neutral words, both ts(35) > 8.9, both ps $< .001$, both ds > 2.1.

RSVP task. The RSVP task was created with the Biopsychology toolbox (Rose, Otto, & Dittrich, 2008) and presented with Matlab software (TheMathworks, Natick, MA) on a 17-inch (43.18-cm) computer screen. On each trial, participants were presented a sequence of 15 words, 2 target words (T1 and T2) written in red and 13 distractor words written in white, at the center of a black screen. Each word was presented for 110 ms with no break between the words. Participants were instructed to attend to the words written in red and to ignore the other words. Immediately after a sequence had been presented, participants were asked to type in the 2 target words. We presented 1, 2, 3, 4, 5, or 6 words between T1 and T2, corresponding to six temporal lags ranging from a stimulus onset asynchrony (SOA) of 220 ms to a SOA of 770 ms. Target words were either neutral or aversive, and four T1–T2 combinations were presented: (a) both targets neutral, (b) T1 neutral, T2 aversive, (c) T1 aversive, T2 neutral, or (d) both targets aversive. There were 8 trials for each factor combination of the 6 (lag) × 4 (T1–T2) conditions, resulting in 192 trials in total, whose occurrence was fully randomized. Each target word was presented twice as T1 and twice as T2. Participants needed about 20 min for task completion.

Procedure

After participants read the study information and provided written consent in their participation, a first saliva sample was collected and a baseline blood pressure measurement was taken. Next, participants were exposed to the SECPT or the control condition; blood pressure was measured during hand immersion. Immediately after the treatment, participants rated on a scale ranging from 0 (*not at all*) to 100 (*very much*) how stressful, painful, and unpleasant they had experienced the previous situation. Another saliva sample was collected, and blood pressure was measured again. After a 20-min break in which they were allowed to read, participants started with the RSVP task. This interval between the SECPT (or control condition) and the RSVP task was chosen because previous studies indicated that the stress hormone cortisol reaches peak levels 20 min after the SECPT (Schwabe, Bohringer, et al., 2008; Schwabe, Haddad, et al., 2008). Before they performed the RSVP task as described earlier, participants were given three training trials (which were exactly the same for all participants). At the end of the session, a last saliva sample was collected.

Seven days after the first experimental session, participants returned to the laboratory; the procedure was repeated but with another version of the RSVP task, and this time participants received the treatment (SECPT or control condition) they had not received during the previous week.

All testing was conducted in the morning between 8:30 and 12:30 a.m. to control for the diurnal rhythm of cortisol, which is characterized by a morning peak and an evening nadir.

Statistical Analyses

We analyzed the subjective assessments of the SECPT and control condition using paired *t* tests, blood pressure, and cortisol responses by separate repeated measurement analyses of variance (ANOVAs), with treatment (SECPT vs. control condition) and time point of measurement as factors. Salivary cortisol data were missing for 2 participants, because these participants did not provide enough saliva for biochemical analyses. Following the analyses of Anderson and Phelps (2001), the six temporal lags between T1 and T2 were segregated in early (SOA $<$ 500 ms) and late (SOA $>$ 500 ms) temporal lags. Performance in the RSVP task was analyzed with a 2 $\times$ 2 $\times$ 2 $\times$ 2 Treatment (SECPT vs. control condition) $\times$ Lag (early vs. late) $\times$ T1 (neutral vs. aversive) $\times$ T2 (neutral vs. aversive) ANOVA. To examine whether a possible stress effect is mediated through the stress hormone cortisol, we calculated the individual cortisol response to stress as difference between the peak and baseline cortisol concentrations. Participants with an increase above the group median (1.7 nmol/L) were classified as high responders, and those whose cortisol increase was below the median as were classified as low responders. Then we performed a 2 $\times$ 2 $\times$ 2 $\times$ 2 Cortisol Response (high vs. low) $\times$ Lag (early vs. late) $\times$ T1 (neutral vs. aversive) $\times$ T2 (neutral vs. aversive) ANOVA. All reported *p* values are two-tailed. The partial eta square (η^2) and Cohen's *d* were used as measures of effect size for ANOVAs and *t* tests, respectively.

Results

Subjective and Physiological Responses to Stress

In the stress condition, all but 2 participants submerged their hands for the full 3 min in ice water. These 2 participants took their hands out of the water after 60 and 110 s, respectively, but did not differ in their stress responses from the rest of the participants.

Subjective assessments. As indicated in Table 1, participants experienced the stress condition as significantly more stressful, painful, and unpleasant than the control condition, all *t*s(35) $>$ 7.5, all *p*s $<$ .001, all *d*s $>$ 1.8.

Blood pressure. The exposure to the SECPT caused a significant increase in systolic blood pressure (for treatment, $F[1, 35] = 8.8$, $p < .001$, $\eta^2 = 0.20$; for Treatment $\times$ Time, $F[2, 70] = 71.0$, $p < .001$, $\eta^2 = 0.67$) and diastolic blood pressure (for treatment, $F[1, 35] = 3.9$, $p = .05$, $\eta^2 = 0.10$; for Treatment $\times$ Time, $F[2, 70] = 44.6$, $p < .001$, $\eta^2 = 0.56$). Table 1 shows that participants had significantly higher blood pressure during the SECPT than during the control condition, whereas there were no differences between the conditions before and after the treatment.

Salivary cortisol. The concentration of the stress hormone cortisol increased in response to the SECPT but not in response to the control condition (for Treatment $\times$ Time, $F[3, 99] = 9.2$, $p < .001$, $\eta^2 = 0.22$; for treatment, $F[1, 33] = 2.2$, $p = .15$, $\eta^2 = 0.06$; see Table 1), suggesting, in line with the subjective and blood pressure data, that participants were stressed after the SECPT but not the control condition.

Table 1
Means (and Standard Errors of the Mean) for Subjective Assessments, Blood Pressure and Salivary Cortisol in the Control and Stress Conditions

Measure	Control	Stress
Subjective assessments		
Stressfulness	5.0 (1.4)	35.8 (4.0)*
Unpleasantness	6.7 (1.3)	54.7 (4.5)*
Painfulness	3.3 (1.5)	56.7 (4.1)*
Systolic blood pressure (in mmHg)		
Before hand immersion	128.1 (2.5)	124.8 (2.3)
During hand immersion	123.9 (2.2)	139.0 (2.3)*
After hand immersion	119.5 (2.2)	119.2 (1.8)
Diastolic blood pressure (in mmHg)		
Before hand immersion	67.8 (1.2)	64.9 (1.4)
During hand immersion	67.7 (1.2)	76.8 (1.3)*
After hand immersion	65.2 (1.0)	63.5 (1.2)
Salivary cortisol (in nnmol/L)		
Baseline	16.4 (1.4)	15.0 (1.8)
1 min posttreatment	16.4 (1.3)	15.8 (1.7)
20 min posttreatment	13.8 (1.0)	20.3 (2.2)*
50 min posttreatment	10.4 (0.8)	12.6 (1.3)

Note. Subjective assessments were measured on a scale ranging from 0 (*not at all*) to 100 (*very much*). Asterisks indicate significant difference between the stress and control conditions, $p < .01$.

Performance in the RSVP Task

The T1 report remained unaffected by stress and the emotionality of T1 and T2 (all *F*s $<$ 2.3). On average, the T1 was correctly reported in 88% of the trials (*SEM* = 1.3).

As expected, participants showed an AB as reflected in a significant increase in T2 detection accuracy from early to late temporal lags (66 vs. 87%), $F(1, 35) = 183.9$, $p < .001$, $\eta^2 = 0.84$. Confirming the assumption that the AB is extended by an emotionally arousing T1, compared with a neutral T1, the ANOVA yielded a significant main effect of T1, $F(1, 35) = 76.8$, $p < .001$, $\eta^2 = 0.69$). As shown in Figure 1A, T2 detection decreased significantly when the T1 was aversive, and this effect was most pronounced at early lags: For Lag $\times$ T1, $F(1, 35) = 15.5$, $p < .001$, $\eta^2 = 0.31$. There was no main effect of T2, $F(1, 35) = 0.32$, $p = .58$, $\eta^2 = 0.03$); however, the AB was attenuated when aversive words were presented as T2: For T2 $\times$ Lag, $F(1, 35) = 17.0$, $p < .001$, $\eta^2 = 0.33$ (see Figure 1B). This effect, however, depended critically on the emotionality of the T1: For the Lag $\times$ T2 $\times$ T1 interaction, $F(1, 35) = 3.9$, $p = .05$, $\eta^2 = 0.10$. An emotionally arousing T2 reduced the AB when the T1 was neutral, $F(1, 35) = 32.8$, $p < .001$, $\eta^2 = 0.38$; but not when the T1 was also emotionally arousing, $F(1, 35) = 2.6$, $p = .13$, $\eta^2 = 0.06$.

Stress before the RSVP task had overall a relatively small but statistically significant positive effect on T2 detection, $F(1, 35) = 4.2$, $p < .05$, $\eta^2 = 0.11$ (see Figure 1C). Participants' T2 detection accuracy increased from 73% to about 78% when they were stressed before task performance. However, the treatment did not

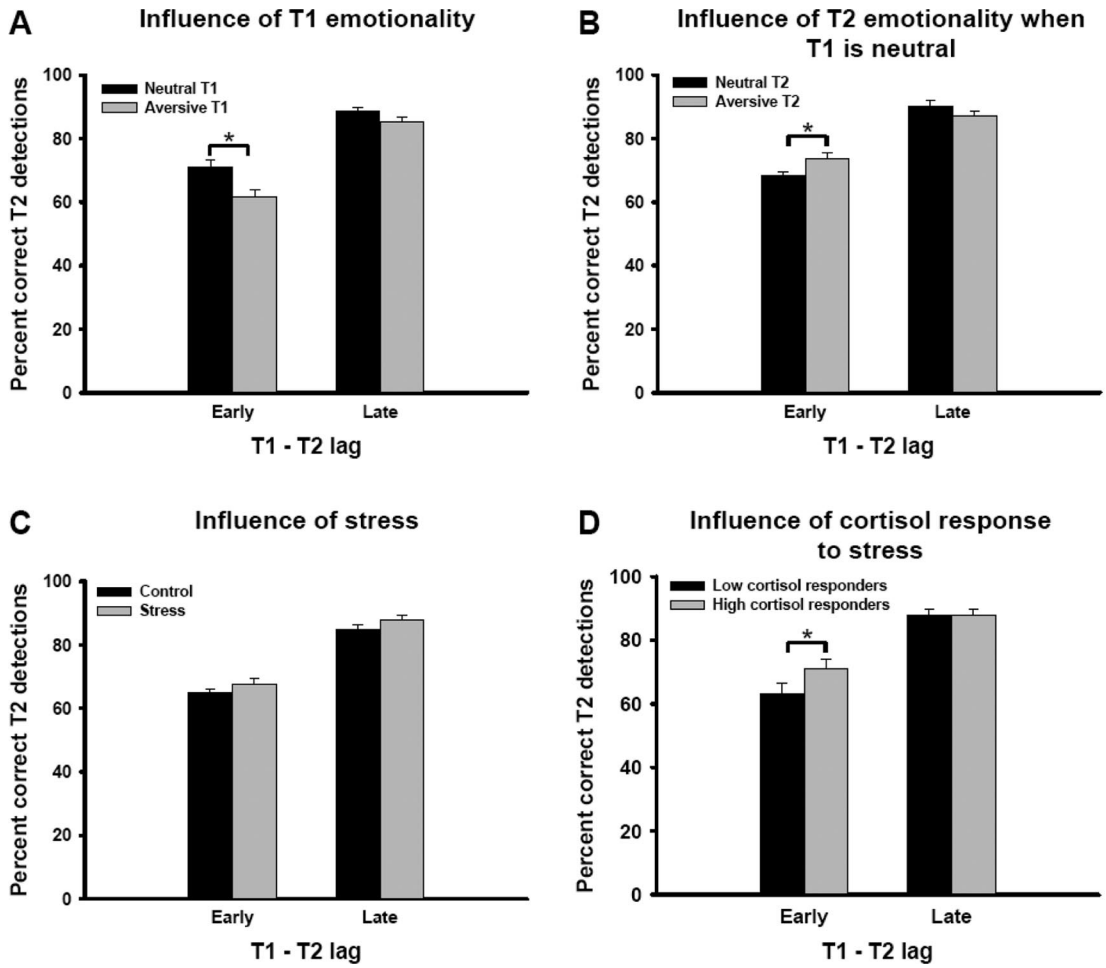

Figure 1. Percent correct detection of the second target (T2) at early (<500 ms) and late (>500 ms) lags as a function of the emotionality (neutral vs. aversive) of the first target (T1) and T2, stress, and the cortisol response to stress. Aversive T1 reduced T2 detection performance at early lag (i.e., it increased the attentional blink) (A) Aversive T2 reduced the attentional blink when the T1 was neutral. (B). Stress slightly enhanced T2 detection at Lag 1 and Lag 2 but did not affect the attentional blink. (C). Participants who showed a large cortisol response to stress (cortisol high responders) showed a reduced attentional blink compared with cortisol low responders. Error bars indicate standard errors of the mean. * $p < .05$.

interact with any of the other factors (all Fs < 2, all ps $> .16$, all η^2s ≤ 0.05).

Cortisol high and low responders (i.e., stressed participants with a cortisol increase above and below the group median, respectively) did not differ in their overall T2 detection, $F(1, 34) = 1.9$, $p = .18$, $\eta^2 = 0.05$; but high cortisol responses to the SECPT attenuated the AB: For the Cortisol Response $\times$ Lag interaction, $F(1, 34) = 10.2$, $p < .01$, $\eta^2 = 0.23$. High cortisol responders outperformed low responders at early lag, $F(1, 34) = 4.6$, $p < .05$, $\eta^2 = 0.12$; but not at late lag, $F(1, 34) = 0.4$, $p = .85$, $\eta^2 < 0.01$ (see Figure 1D), regardless of the emotionality of T1 and T2 (all Fs < 2.1). Moreover, there was a significant negative correlation between the cortisol response to stress and the magnitude of the AB (calculated as T2 detection at late lag $-$ T2 detection at early lag; $r = -.33$, $p < .05$) suggesting that higher cortisol responses to stress were associated with a reduced AB.

Discussion

In line with several previous studies, we found that participants have difficulties in identifying T2 when presented within 500 ms after T1 (Broadbent & Broadbent, 1987; Mathewson et al., 2008; Raymond et al., 1992) and that this AB was reduced when the T2 was emotionally arousing (Anderson & Phelps, 2001; Keil & Ihssen, 2004). The novel finding presented here is that the blink-reducing effect of an emotionally arousing T2 disappears when the T1 is also emotional, suggesting that the emotionality of the T1 is a critical factor in the emotional modulation of the AB. Given that emotionally arousing stimuli attract substantial attentional resources (Dijksterhuis & Aarts, 2003), this finding supports theories assuming that the AB is mainly due to the processing of T1, which makes attentional resources unavailable for the T2 (Chun & Potter, 1995; Jolicouer, 1999). At the same time, the present results argue against the view that emotionally

arousing stimuli are freed from attentional limitations (Anderson, 2005) because otherwise the detection of an emotionally arousing T2 should have been insensitive to the emotionality (processing demands) of T1. Rather, our findings suggest that emotionally arousing T1s capture and hold attention (Mathewson et al., 2008), thus leaving only few attentional resources for allocation to T2, regardless of whether the T2 is neutral or emotionally arousing.

Beyond the effects of the emotionality of the presented stimuli, we demonstrate that attention performance in an RSVP task is influenced by the emotional state of the individual. Participants exposed to stress before the RSVP task showed slightly enhanced T2 detection performance, both at early and late temporal lags between T1 and T2. This is consistent with Callaway and Thompson's (1953) notion of focused attention under stress and may provide an explanation for the memory-enhancing effects of stress administered before learning that was observed in some studies (Nater et al., 2007; Schwabe, Bohringer, et al., 2008). Pharmacological studies provided evidence that the neurotransmitter noradrenaline, which is also released in response to stress, facilitates selective attention (Aston-Jones & Cohen, 2005; Clark, Geffen, & Geffen, 1986; de Martino, Strange, & Dolan, 2008). In the present study, participants performed the RSVP task 20 min after the stressor, when cortisol reached peak levels but noradrenaline, as reflected in the blood pressure changes, returned to baseline already. Thus, noradrenaline was most likely not the driving force behind the observed stress-induced attention enhancement. Our finding, that the AB correlated negatively with the cortisol increase in response to stress, points to a crucial role of the stress hormone cortisol, suggesting that the noradrenaline and cortisol stress systems act—at different time points—in concert to enhance attention.

At first glance, the present finding that high cortisol responses to stress were associated with a reduced AB may be seen as in conflict with recent evidence showing an increased AB in an anxious mood state (Jefferies, Smilek, Eich, & Enns, 2008). However, anxiety does not necessarily elicit an increase in cortisol. Moreover, arousal parameters such as blood pressure were already in the normal range again (i.e., participants were most likely not anxious anymore) when the RSVP task started.

Stress effects on learning and memory are most pronounced for emotional material (for a review and examples of stress effects on neutral material, see Wolf, 2008). Moreover, neuropsychological evidence suggests that the emotional modulation of the attentional blink relies on an intact amygdala (Anderson & Phelps, 2001), the activity of which is known to be enhanced by stress (Diamond, Campbell, Park, Halonen, & Zoladz, 2007). Therefore, we hypothesized that stress would especially affect the detection of emotional targets. This, however, was not the case. Stress enhanced attention for neutral and emotional stimuli to the same extent. Similarly, the pharmacological blockade of β-adrenergic receptors in a previous study impaired attention regardless of the emotionality of the target items (de Martino et al., 2008). This might suggest that the neural mechanisms underlying stress (hormone) effects on attention, learning, and memory of neutral and emotional material differ, most likely because of the different time frames (milliseconds vs. minutes to days) of perceptual and recollective experiences. Future studies could address this assumption by testing the subsequent memory performance for neutral and emotional stimuli presented in a RSVP stream.

This first study on the impact of stress on attention in a RSVP task examined only male participants to keep the sample homogeneous with respect to sex hormones, which are known to change the neuroendocrine response to stress (Kirschbaum et al., 1999). In the face of evidence suggesting sex differences in cognition and the effect of stress on cognition (Cahill, 2006; Wolf, Schommer, Hellhammer, McEwen, & Kirschbaum, 2001), future studies are needed to corroborate our findings in women.

In conclusion, the results of this experiment demonstrate that attention is influenced by both the emotional state of the individual and the emotionality of the presented material. We show that humans are endowed with capabilities enhancing the quick and efficient detection of stimuli significant to the organism. These capabilities, however, appear to reach their limits when two such stimuli occur in rapid succession.

References

Anderson, A. K. (2005). Affective influences on the attentional dynamics supporting awareness. *Journal of Experimental Psychology: General, 134,* 258–281.

Anderson, A. K., & Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature, 411,* 305–309.

Arnell, K. M., Killman, K. V., & Fijavz, D. (2007). Blinded by emotion: Target misses follow attention capture by arousing distractors in RSVP. *Emotion, 7,* 465–477.

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus-coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28,* 403–450.

Broadbent, D. E., & Broadbent, M. H. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics, 42,* 105–113.

Cahill, L. (2006). Why sex matters for neuroscience. *Nature Reviews Neuroscience, 7,* 477–484.

Callaway, E., & Thompson, S. V. (1953). Sympathetic activity and perception. *Psychosomatic Medicine, 15,* 443–455.

Christianson, S. A. (1992). *The handbook of emotion and memory.* Hillsdale, NJ: Erlbaum.

Chun, M., & Potter, M. C. (1995). A two-stage model for multiple target detection in serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 109–127.

Clark, C. R., Geffen, G. M., & Geffen, L. B. (1986). Role of monoamine pathways in attention and effort: Effects of clonidine and methylpenidate in normal adult humans. *Psychopharmacology, 90,* 35–39.

de Martino, B., Strange, B. A., & Dolan, R. J. (2008). Noradrenergic neuromodulation of human attention for emotional and neutral stimuli. *Psychopharmacology, 197,* 127–136.

Diamond, D. M., Campbell, A. M., Park, C. R., Halonen, J., & Zoladz, P. R. (2007). The temporal dynamics model of emotional memory processing: A synthesis on the neurobiological basis of stress-induced amnesia, flashbulb and traumatic memories, and the Yerkes-Dodson law. *Neural Plasticity, 2007,* 60803.

Dijksterhuis, A., & Aarts, H. (2003). On wildebeests and humans: The preferential detection of negative stimuli. *Psychological Science, 14,* 14–18.

Jefferies, L. N., Smilek, D., Eich, E., & Enns, J. T. (2008). Emotional valence and arousal interact in attentional control. *Psychological Science, 19,* 290–295.

Joels, 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.

Jolicouer, P. (1999). Dual-task interference and visual encoding. *Journal of*

Experimental Psychology: Human Perception and Performance, 25, 596–616.

Keil, A., & Ihssen, N. (2004). Identification facilitation of emotionally arousing verbs during the attentional blink. *Emotion, 4,* 23–35.

Kirschbaum, C., Kudielka, B. M., Gaab, J., Schommer, N. C., & Hellhammer, D. H. (1999). Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituary-adrenal axis. *Psychosomatic Medicine, 61,* 154–162.

Kuhlmann, S., Piel, M., & Wolf, O. T. (2005). Impaired memory retrieval after psychosocial stress in healthy young men. *Journal of Neuroscience, 25,* 2977–2982.

Lupien, S. J., Lecours, A. R., Lussier, I., Schwartz, G., Nair, N. P., & Meaney, M. (1994). Basal cortisol levels and cognitive deficits in human aging. *Journal of Neuroscience, 14,* 2893–2903.

Mathewson, K. J., Arnell, K. M., & Mansfield, C. A. (2008). Capturing and holding attention: The impact of emotional words in rapid serial visual presentation. *Memory & Cognition, 36,* 182–200.

Nater, U. M., Moor, C., Okere, U., Stallkamp, R., Martin, M., Ehlert, U., & Kliegel, M. (2007). Performance on a declarative memory task is better in high than low cortisol responders to psychosocial stress. *Psychoneuroendocrinology, 32,* 758–763.

Putman, P., Hermans, E. J., Koppeschaar, H., van Schijndel, A., & van Honk, J. (2007). A single administration of cortisol acutely reduces preconscious attention for fear in anxious young men. *Psychoneuroendocrinology, 32,* 793–802.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860.

Roelofs, K., Bakvis, P., Hermans, E. J., van Pelt, J., & van Honk, J. (2007). The effects of social stress and cortisol responses on the preconscious selective attention to social threat. *Biological Psychology, 75,* 1–7.

Rose, J., Otto, T., & Dittrich, L. (2008). The Biopsychology-Toolbox: A free, open-source Matlab-toolbox for the control of behavioral experiments. *Journal of Neuroscience Methods, 175,* 104–107.

Schwabe, L., Bohringer, A., Chatterjee, M., & Schachinger, H. (2008). Effects of pre-learning stress on memory for neutral, positive and negative words: Different roles of cortisol and autonomic arousal. *Neurobiology of Learning and Memory, 90,* 44–53.

Schwabe, L., Haddad, L., & Schachinger, H. (2008). HPA axis activation by a socially evaluated cold pressor test. *Psychoneuroendocrinology, 33,* 890–895.

Shapiro, K. L., Arnell, K. M., & Raymond, J. E. (1997). The attentional blink. *Trends in Cognitive Sciences, 1,* 291–296.

Smith, S. D., Most, S. B., Newsome, L. A., & Zald, D. H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion, 6,* 523–527.

Wolf, O. T. (2008). The influence of stress hormones on emotional memory: Relevance for psychopathology. *Acta Psychologica (Amsterdam), 127,* 513–531.

Wolf, O. T., Schommer, N. C., Hellhammer, D. H., McEwen, B. S., & Kirschbaum, C. (2001). The relationship between stress-induced cortisol levels and memory differs between men and women. *Psychoneuroendocrinology, 26,* 711–720.

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