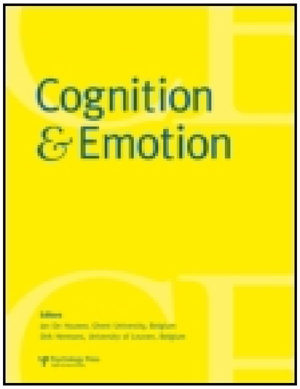

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Stress induces a functional asymmetry in an emotional attention task

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BRIEF REPORT

Stress induces a functional asymmetry in an emotional attention task

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Anxiety is associated with an attentional bias towards angry faces. This effect is most pronounced when the face is presented in the left visual hemifield (LVHF), suggestive of a right hemisphere involvement. Little is known about the modulation of this attentional bias in situations of acute stress. In the current study 38 male participants were randomly allocated to a stress (Trier Social Stress Test; TSST) or a non-stressful control condition. Afterwards they performed an emotional dot-probe paradigm. Stress induced negative affect and a rise in salivary cortisol. Stress caused a pattern of functional asymmetry in the short stimulus onset asynchrony (SOA) interval, which was absent in the control group. Stressed participants responded faster to angry faces presented to the LVHF, but responded faster to happy faces presented to the right VHF. This could suggest that stress influences interhemispheric transfer of information that is relevant for emotion processing.

Keywords: Stress; Cortisol; Valence; Hemispheric asymmetry; Attention; Dot-probe paradigm.

Humans have evolved universal mechanisms to deal with the perception of threat. For “social animals” like ourselves, potential causes of threat have not only been related to animate or inanimate contingencies like predation or blizzards, but also to conspecifics with whom we compete for resources and mates. Thus, social threat is a stressful event that is not only conveyed by verbal content but also by facial expressions of negative emotions, particularly anger. Rapid and accurate detection of such social threat signals has therefore been a target of natural and sexual selection (Oatley & Johnson-Laird, 1987).

Individual differences in social threat perception depend on a variety of conditions, including current affect and personality traits. Mogg and

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Bradley put forth the idea that a valence evaluation system (mediated by the amygdala) is responsible for the evaluation of stimuli as regards their threat value, and that this system feeds into a goal engagement system, which allocates resources for cognitive processing and behaviour (Mogg & Bradley, 1998).

In experimental settings, attention to facial expressions of anger has been explored using multiple tasks (Cisler & Koster, 2010). In the emotional dot-probe task, participants simultaneously view a neutral and an emotionally salient stimulus, one of which is replaced by a dot after a certain presentation time (referred to as "stimulus onset asynchrony"; SOA). The participants are asked to indicate the location of the dot (right or left) as quickly as possible. A faster reaction time (RT) indicates the orientation of attention towards the preceding stimulus (Cisler & Koster, 2010). Individuals with social phobia or heightened anxiety have faster RT when the dot location is congruent with the location of the threat stimulus. This is referred to as the "engagement effect". It is especially evident when the stimuli are presented at shorter SOAs (between 100 and 300 ms; Arguedas, Green, Langdon, & Coltheart, 2006; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) and it is assumed to reflect an automatic attentional bias towards threat (Cisler & Koster, 2010; Mogg & Bradley, 1998). Early threat detection mechanisms seem to be more effective when the threatening cues are presented in the left visual hemifield (lVHF) suggesting a right-hemispheric advantage in the processing of threatening stimuli (Mogg & Bradley, 2002).

A "disengagement effect" is observed when participants have to detect dot probes opposite to an expressive face, which is detectable at longer SOAs (Arguedas et al., 2006). This reflects strategic (top down) attentional control processes (Cisler & Koster, 2010). Those strategic processes might be less sensitive to acute stress.

As outlined above, social threat is a stressful event, but the role of acute stress and the associated neuroendocrine response on threat processing is less clear. Stress activates the sympathetic nervous system (SNS) resulting in heightened noradrenergic arousal (Wolf, 2008). A second somewhat slower response consists of an increased activity of the hypothalamic–pituitary–adrenal (HPA) axis. This in turn leads the adrenal gland to produce cortisol (Wolf, 2008). The presence of glucocorticoid receptors in the hippocampus, amygdala, and prefrontal cortical areas, which are known to be active when dealing with social threat, could suggest that these receptors play a role in the stress-associated modulation of the processing of social stimuli (Wolf, 2008). In addition (as outlined in the discussion) stress-associated increases in several progesterone-derived neurosteroids have to be considered (Reddy, 2010).

Several studies have suggested that stress can facilitate selective attention towards threat or emotional distractors (Mogg, Mathews, Bird, & Macgregor-Morris, 1990; Oei et al., 2011). However, there is also evidence to suggest that stress or cortisol is associated with reduced attention towards subliminally presented or task-irrelevant threatening stimuli (e.g., Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007; van Honk et al., 1998). A review is given by (Putman & Roelofs, 2011). It is conceivable that stress onset and its associated rise in noradrenalin can direct early attention towards threatening stimuli to facilitate rapid judgements about the source of threat. Later on cortisol might reverse this pattern, thereby preparing the organism to cope with the challenge (Putman & Roelofs, 2011). Moreover, the stress-induced cortisol rise has been related to reduced approach–withdrawal behaviour (Roelofs, Elzinga, & Rotteveel, 2005). However, based on pharmacological studies it has been suggested that cortisol acutely enhances processing of goal-relevant emotional information thereby promoting approach–avoidance behaviour and facilitating active coping behaviour (Putman & Roelofs, 2011).

Studies indicate that the cortical regulation of cortisol secretion in emotional situations is under control of the right hemisphere (Wittling, 1997). This is supported by neuroimaging findings demonstrating that a psychosocial laboratory stressor produced increased activity in the right prefrontal cortex that was associated with the cortisol stress response (Wang et al., 2005). However, studies investigating the effects of stress on emotional attention have so far typically not explicitly focused on the issue of lateralisation.

In the present study, we sought to examine the influence of social stress-induced cortisol on attentional biases of threat perception in a dot-probe experiment. Specifically, we hypothesised, based on findings in fearful participants and phobic patients, that acute social stress would facilitate rapid threat detection. Based on previous findings (Mogg & Bradley, 2006), we expected an enhanced engagement effect for threatening faces, which might be especially pronounced in the short SOA (200 ms). In addition, we hypothesised that acute stress would not influence the disengagement effect. Finally, we expected stress to produce a right-hemispheric advantage resulting in a larger engagement effects for threatening stimuli presented to the left visual field (see Mogg & Bradley, 2002; Wang et al., 2005).

METHODS

Participants

Thirty-eight male students were recruited. Twenty were randomly assigned to the stress group and 18 to the control group. Only men were included to avoid menstrual-cycle effects on the cortisol stress response and its cognitive consequences. Regular smoking, a body mass index (BMI) out of the normal range (below 19 or above 26 kg/m^2) and acute or chronic diseases led to exclusion. In addition, we excluded students who had previously participated in the TSST. All participants refrained from smoking, caffeine, meals and all kinds of beverages except water at least one hour prior to testing. The study was approved by the Ethic Committee of the German Psychological Association (DGPS) and all students provided written informed consent before participation. Participants received a small financial reimbursement for study participation.

Procedure and stress induction

Experimental sessions started between 2 p.m. and 3 p.m. First, participants signed the written informed consent form and filled out a demographic questionnaire. Afterwards they rested for approximately 30 minutes before they collected the first saliva sample (baseline). Subsequently, they were taken to another room where the stress or control task (see below) was performed.

Stress and control treatment. The Trier Social Stress Test (TSST) was used to induce a stress response. After a five-minute preparation period participants have to perform an oral presentation and an arithmetic task for a total of ten minutes in front of a panel (one woman and one man dressed in white coats) that deliberately refrains from positive feedback. The presentation is video-taped. The TSST is known to reliably elicit a cortisol stress response. The non-stressful control condition, called the Placebo-TSST (Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009), also consists of an oral presentation and an arithmetic task but participants do not perform in front of an audience and are not video-taped. It thus lacks the stressful components of the TSST (social evaluative threat and uncontrollability) and does not elicit a cortisol stress (Het et al., 2009).

Neuroendocrine and psychometric stress measurement. Saliva samples were taken at four different times; at baseline and 1 min, 10 min and 30 min after completion of the TSST or Placebo-TSST. Saliva was collected using Salivette collection devices (Sarstedt, Nuernbrecht, Germany) and kept in a freezer until biochemical analysis. Free cortisol levels served as a measure of HPA activity and were determined by a commercially available immunoassay (IBL, Hamburg, Germany). Inter- and intra-coefficients of variation were below 10%.

Furthermore, the German version of the Positive and Negative Affect Schedule (PANAS) was applied to assess positive and negative affect. The questionnaire was applied before and after the respective experimental treatment.

Dot-probe task

Ten minutes after TSST or Placebo-TSST, when cortisol levels typically peak, participants performed an emotional dot-probe task. The task was similar to the version described by Arguedas and colleagues (Arguedas et al., 2006). Participants were placed in front of a computer screen (approximately 60 cm) and were provided with a head holder. The stimuli consisted of 30 photographs of faces (five men and five women), which were selected from the Karolinska Directed Emotional Faces database (KDEF). The faces expressed positive (happy), threatening (angry) and neutral emotions, and were presented in pairs of the same individual, i.e., one emotional (angry or happy) and the neutral face from one person. All pictures measured 9×13 cm, with 384 pixels (height) $\times$ 256 pixels (width) and a distance of 35 mm between the inner edges of a pair of photographs. The dot-probe stimulus was a black dot (diameter: 7 mm), which was displayed on a white screen.

The task included 10 practice and 80 experimental trials for two SOAs (200 ms and 500 ms). In the experiment, faces of happy–neutral and angry–neutral pairs were presented, whereby half of the emotional photographs were presented to the right VHF and half to the left VHF. The dot probe appeared equally frequently at the location of the emotional stimuli as at the location of the neutral stimuli, so that no predictive statements about the location of the dot could be made. Based on the two SOAs, two experimental tasks (one for each SOA) were constructed. In order to rule out practice effects, the presentation of the two SOAs was counterbalanced and the trials within one SOA were randomised.

Each trial started with a fixation cross in the middle of the computer screen. After 1,000 ms, it was replaced by the pair of photographs, with one stimulus on either side of the screen. Following the respective SOA (200 ms or 500 ms), the stimuli disappeared and a dot probe popped up in the location of one of the stimuli. Participants were required to indicate the location of the dot as quickly and accurately as possible by pressing a key on the keyboard. After the participants specified the location of the dot probe, the next trial was presented after a 500 ms inter-stimulus interval.

Statistical analysis

Psychometric, neuroendocrine and behavioural data were analysed using mixed-model analyses of variance (ANOVAs) as described in detail in the respective result sections. Greenhouse–Geisser corrections were applied when indicated. Post hoc tests were performed using Bonferroni-adjusted *t*-tests.

RESULTS

Affective response to stress

A repeated-measurement ANOVA of the PANAS scores with the factor Time (pre- and post-treatment) and the between-subject factor Group (control group vs. stress group) was computed separately for negative and positive affect. The analysis revealed a significant Time $\times$ Group interaction for negative affect, $F(1, 36) = 11.66$, $p < .01$. The two groups did not differ in negative affect before treatment (control group: 13.06 ± 0.59; stress group 13.90 ± 0.79). However, a significant difference was found afterwards, with the experimental group reporting more and the control group less negative affect (control group: 10.89 ± 0.29; stress group 16.05 ± 1.25). The ANOVA with positive affect did not reveal a significant effect of stress.

Cortisol response to stress

Due to an insufficient amount of saliva, cortisol concentrations were missing from two participants. With the remaining 36 participants, a repeated-measurement ANOVA with the factors Time (baseline, +1 min, +10 min, +30 min) and Group (control group vs. stress group) was performed. As expected, the analysis of saliva samples revealed higher cortisol concentrations in the stress (TSST) group (see Figure 1). The ANOVA indicated a main effect of Group, $F(1, 34) = 19.33$, $p < .001$, and a significant Time $\times$

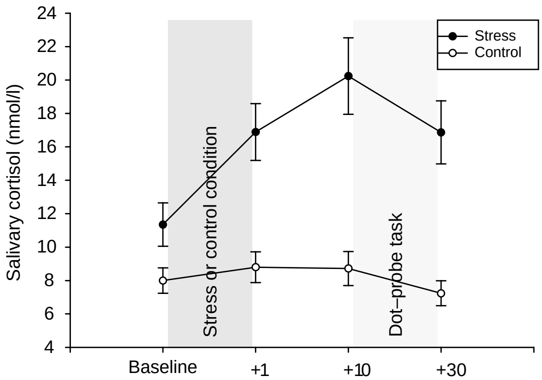

Figure 1. *Cortisol response to the TSST and the control condition (Mean ± SEM). A significant interaction between stress and time occurred in the ANOVA. Follow-up t-tests revealed significant differences between the TSST and control group at measurements + 01, + 10 and + 25. The dot probe was presented between the measurement time points + 10 and + 25.*

Group interaction, $F(3, 102) = 9.21$, $p < .001$. Post hoc tests using Bonferroni-adjusted *t*-tests revealed that the stress group (compared to the control group) displayed significantly larger cortisol concentrations at all three post-treatment time points ($p < .001$).

Dot-probe task

Accuracy. As expected, response accuracy was high. The amount of errors ranged between 4.7 and 0.5% depending on the specific stimulus combination. A mixed-model ANOVA with Group (stressed group vs. control group) as between-subject factor and four within-subject factors was conducted; SOA (200 ms vs. 500 ms), Hemifield (location of the emotional face: right vs. left VHF), Valence (angry vs. happy face), and Dot Location (same location as the emotional face vs. different location as the emotional face). Results revealed that fewer correct responses (9.77 ± 0.04 compared to 9.86 ± 0.03 out of a maximum of 10 correct trials per stimulus combination) were given in the short SOA, $F(1, 36) = 6.59$, $p < .05$. Notably, no effect (main effect as well as all possible interactions) occurred for the factor Group (all *p*s > .10).

Response time. RTs of correct responses served as indicator for the attentional bias towards emotional stimuli (threatening faces vs. happy faces). Again a mixed-model ANOVA with Group (stressed group vs. control group) as a between-subject factor and four within-subject factors was conducted; SOA (200 ms vs. 500 ms), Hemifield (location of the emotional face: right vs. left VHF), Valence (angry vs. happy face), and Dot Location (same location as the emotional face vs. different location as the emotional face).

The analysis revealed a main effect of Dot Location, $F(1, 36) = 8.85$, $p < .01$. Overall, participants responded more quickly when the dot replaced an emotional face compared to a neutral fact (0.397 ± 0.01 s, compared to 0.401 ± 0.01 s). This effect was not modulated by valence. The Dot Location by Valence interaction was not significant. Stressed participants were slightly slower than controls (0.388 ± 0.015 s, compared to 0.401 ± 0.014 s), but this differences was not significant ($p = .29$). Most interestingly, a significant four-way interaction between Group, Valence, Hemifield and Dot Location occurred, $F(1, 36) = 7.74$, $p < .01$.

Since previous studies indicated that effects of anxiety or delusion proneness on attentional biases in the dot-probe paradigm are most pronounced for short SOAs (Arguedas et al., 2006; Mogg & Bradley, 2006), we decided to break this interaction down further towards the two employed SOAs, the same analysis was run for the two SOAs separately (200 ms versus 500 ms). For the short SOA (200 ms) the significant four-way interaction between Group, Valence, Hemifield and Dot Location remained significant, $F(1, 36) = 6.88$, $p < .05$. In contrast for the long SOA the four-way interaction was not significant, $F(1, 36) = 0.63$, $p = .43$.

In order to investigate this complex interaction further we separated—in line with previous work (see Arguedas et al., 2006)—engagement effects (dot at the same location as the emotional face) from disengagement effects (dot opposite to the emotional face).

Engagement effects. Analysis of the engagement effects for the short SOA revealed a significant three-way interaction Group × Valence × Hemifield, $F(1, 36) = 4.42$, $p < .05$. As illustrated in Figure 2, participants in the control group did not show an interaction between the valence of the faces and the hemifield where the emotional faces were presented. An ANOVA (Valence × Hemifield) revealed no significant interaction between VHF and valence, $F(1, 17) = 0.004$, $p = .95$. In the stressed group a different picture emerged. When the dot probe matched the location of the angry face, stressed participants reacted descriptively faster when it was presented to the left hemifield (i.e., processed by the right hemisphere). However, RTs towards happy faces were descriptively faster when presented to the right hemifield (left hemisphere processing). In line with this, an ANOVA (Valence × Hemifield) revealed a significant interaction between Hemifield and Valence, $F(1, 19) = 6.44$, $p < .05$, within the stress group. Further analyses for angry and happy faces only failed to find a significant effect of the factor Hemifield.

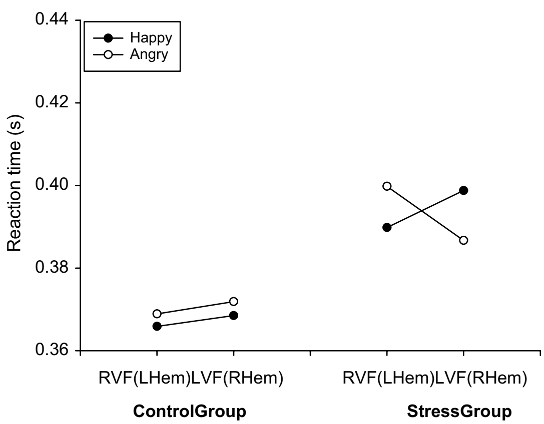

Figure 2. *Effects of stress on the engagement component of the dot-probe paradigm in the short (200 ms) SOA. Stressed participants showed a valence-specific pattern of hemispheric asymmetry, which was not present in controls. Stressed participants responded descriptively faster when the dot replaced an angry face presented to the left visual field (LVF). In contrast the response to the dot replacing the happy face was descriptively faster, if it was presented to the right visual field (RVF). Control participants responded descriptively (but not significantly) overall quicker, but did not show the asymmetric response pattern observed in the stress group.*

Disengagement effects. For the analysis of the disengagement effects the same ANOVA as described above was computed for those trials where the dot replaced the neutral face (where the dot was opposite from the emotional face). This analysis did not reveal any effects (neither main effect nor interactions) with the factor Group (data not shown).

DISCUSSION

Rapid detection of potentially dangerous situations has been a target of natural selection to kick off fight or flight responses. In social animals scenarios involving threat specifically include encounters with conspecifics. It has been suggested that social stress causes an attentional bias towards threat cues (Mogg et al., 1990) or emotional distractors (Oei et al., 2011). However, in contrast, the stress hormone cortisol may inhibit the processing of goal-irrelevant threatening information (Putman & Roelofs, 2011). Despite the relevance of this issue, the number of studies in this area employing a potent laboratory stressor is actually rather low (see, however, Roelofs et al., 2005).

In line with predictions, in the short SOA condition, socially stressed individuals responded descriptively faster to dot probes that replaced negative faces in the left VHF (right hemisphere) and positive faces in right VHF (left hemisphere), respectively. In trials with longer SOAs (500 ms) this asymmetry disappeared. These results indicate an emotional engagement effect in the socially stressed group that displayed a pattern of complementary asymmetries (e.g., asymmetry is opposing for happy and threatening faces). This effect occurred for the short SOA only indicating that in our study stress modulated rapid emotional engagement effects only. These findings mirror findings in spider-fearful participants showing that their attentional bias towards spiders was detectable during a short (200 ms) but not during longer (500 ms and 2,000 ms) SOAs (Mogg & Bradley, 2006).

It has to be noted that in our experiment stressed participants did not respond faster to the threatening cues when compared to the control group. In fact they tended to respond slower overall. However, stress induced intra-individual changes of threat-associated processing (e.g., a stronger difference in response times to threatening stimuli presented to the left vs. right visual hemifield).

The observation that acutely stressed participants responded faster to threat cues compared to the happy cues presented in the left VHF fits well to previous reports of such an asymmetrical response pattern in anxious individuals (e.g., Mogg & Bradley, 1998). Our results are also in line with human neuroimaging studies showing increased activity of the right prefrontal cortex in response to stress (Wang et al., 2005).

Interestingly, an engagement effect was also found in the stressed group as regards the detection of positive emotions in the short SOA condition that was lateralised to the opposite—the right—VHF, that is, left hemisphere. Here the response to happy faces was more rapid than the response to angry faces. This lateralised response pattern lead to a significant valence by hemifield interaction in the stress group, which was absent in the control group. Thus, rather than inducing a general bias towards threatening stimuli as suggested by some previous studies using a shorter and milder stressor (Mogg et al., 1990), in our study social stress induced a lateralised responding to emotional faces. The absence of a (lateralised) threat detection bias in the control group is in line with previous findings in non-anxious healthy controls (Mogg, Bradley, de Bono, & Painter, 1997).

When comparing our findings with previous studies on this topic it is important to emphasise that our stressor activates the sympathetic nervous system (SNS) as well as the HPA axis (Het et al., 2009). It is thus somewhat difficult to compare our current findings with previous studies using different (typically milder and/or longer acting) stressors (e.g., Ellenbogen, Schwartzman, Stewart, &Walker, 2002). Pharmacological cortisol studies (see Putman & Roelofs, 2011, for a review) suggest the effects of cortisol on emotional attention depend on the task relevance of the stimuli (distractor or targets), such a differentiation is however difficult to conceptualise for the dot-probe task. Our findings provide further support for a context-dependency of the effects of stress (or cortisol) on emotional attention. Previous studies have illustrated that the effects of stress appear to depend crucially on contextual factors (such as for instance task-relevance of the stimuli; see Putman & Roelofs, 2011). Our current results illustrates that hemifield is another factor that can modulate stress effects.

Acute social stress did not influence the disengagement effect. The latter finding appears to be in contrast to previous studies using milder stressors (Ellenbogen et al., 2002) or relating basal endogenous cortisol concentrations to avoidance (van Honk et al., 1998). Stress intensity or differences in the used emotional tasks (e.g., differences in the SOAs used by Ellenbogen et al., 2002) might explain these discrepancies.

Stressed participants reacted faster to the dot-probe location in the short SOA condition presented to the left or the right VHF for angry or happy faces, respectively. Put another way, stress induced a specialisation of the right hemisphere for angry, and of the left hemisphere for happy faces. This fits to the "valence hypothesis", which states that hemispheres differ according to emotional valence with the right brain dominant for negative, and the left brain dominant for positive emotions (Davidson, 2003). However, the valence hypothesis blends affective (negative, positive) and motivational (avoidance, approach) dichotomies (Harmon-Jones, Gable, & Peterson, 2010). Using emotions like happiness or fear, it is impossible to solve this confound. Anger, however, is an emotional state that is negative but related to approach. Using experimental manipulations of anger, it was possible to show that left and right hemispheric processes are, indeed, associated to the dimensions of approach (left) and avoidance (right) rather than positive and negative affect, respectively (Harmon-Jones et al., 2010). Van Honk and Schutter (2006), for example, could reveal that repetitive transcranial magnetic stimulation (rTMS)-induced inhibition of the left dorsolateral prefrontal cortex reduces anger.

It is important to note that the emotional dote-probe paradigm with angry faces is thought to capture threat biases (Cisler & Koster, 2010; Mogg & Bradley, 2002; Mogg et al., 1997). Thus for the negative emotion fear (induced by threatening faces), which is accompanied by a withdrawal motivation, the different models (Davidson, 2003; Harmon-Jones et al., 2010; van Honk & Schutter, 2006) make the same prediction (e.g., right hemisphere advantage for the processing of threatening faces).

An explanation for our findings could be that stress reduces the interhemispheric connectivity, such that approach and avoidance-related motivations are differentially processed in the two hemispheres (Davidson, 2003; Harmon-Jones et al., 2010). Acute stress results in a rapid decrease of GABAergic neurotransmission and subsequently an important recovery of GABAergic transmission is observed (Barbaccia et al., 1996). Thus, stress increases $GABA_A$ efficacy via neurosteroids within the time frame of our testing. The increase of GABAergic transmission could increase the inhibition of the contralateral hemisphere after callosal activation (Hausmann & Güntürkün, 2000). Cerebral asymmetries reflect callosal mechanisms of reciprocal inhibition in which a stimulus-specific activation of one of the hemispheres inhibits the other one during task processing. Indeed, task-specific activation of one hemisphere is usually associated with an increased asymmetry and a decrease of activation of the contralateral homotopic areas. Acute stress via neurosteroids- or cortisol-related mechanisms increases GABAergic transmission. This effect could decrease reaction times but increase the inhibitory cross talk of the hemispheres, resulting in a salient asymmetry pattern as observed in our stressed participants.

In sum the present experiment indicates that acute psychosocial stress induces a pattern of complementary asymmetry during an emotional attention task in young healthy men. This effect was only seen for short SOAs and only for the engagement effect. While the effect for angry faces mirrors findings in participants with high anxiety or patients with anxiety disorders the observations for happy faces indicate that stress increases in fact induce a cerebral lateralisation in this task. Stress is associated with reduced prefrontal capacities (Wolf, 2008). Given the known advantages of lateralised processing, e.g., increased efficiency, improved ability to perform dual tasks (Vallortigara, 2006), such a lateralised response mode during times of stress might thus be adaptive from an evolutionary point of view.

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