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The effects of social stress and cortisol responses on the preconscious selective attention to social threat

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Abstract

The purpose of the present study was to investigate the effects of social stress and stress-induced cortisol on the preconscious selective attention to social threat. Twenty healthy participants were administered a masked emotional Stroop task (comparing color-naming latencies for angry, neutral and happy faces) in conditions of rest and social stress. Stress was induced by means of the Trier social stress test. Based on the stress-induced increase in cortisol levels, participants were allocated post hoc (median-split) to a high and low responders group. In contrast to low responders, high responders showed a negative or avoidant attentional bias to threat (i.e. shorter latencies for angry than neutral faces) in the rest condition. Most importantly, although low responders became avoidant, the high responders became vigilant to the angry faces after stress induction. There were no such effects for happy faces. Our findings are in line with previous studies in both animals and humans, that associate high glucocorticoid stress-responsiveness with diminished avoidance and prolonged freezing reactions during stress.

Keywords: Cortisol; Avoidance; Emotional Stroop task; Masked angry faces; Trier social stress test; Selective attention

1. Introduction

Social submissiveness and avoidance in social situations is associated with hypercortisolism and increased activity of the hypothalamic pituitary adrenal (HPA)-axis in primates (e.g. Golub et al., 1979; Sapolsky, 1990; Sassenrath, 1970). In humans the relation between social avoidance tendencies and HPA-axis activity has been studied less extensively and the findings are less unequivocal. Some recent studies found significant relations between self-reports of avoidance motivation, such as low self-esteem, negative affect and social submissiveness on the one hand and elevated cortisol responses to social stress on the other hand (e.g. Gruenewald et al., 2004; Pruessner et al., 1997). Also Hessl et al. (2006) found a significant relation between gaze avoidance and cortisol responses during a social stress test in healthy children. In contrast, a study among army recruits (Hellhammer et al., 1997) demonstrated socially dominant rather than socially submissive army recruits to exhibit elevated cortisol responses to social stress. Finally, Buss et al. (2003) studied avoidance reactions (observations of fear, sadness and withdrawal) in 6-month-old infants during a social challenge task and found no relation with cortisol responses during the task. In most of these studies social avoidance tendencies were indirectly measured using self-report questionnaires of withdrawal motivation (Gruenewald et al., 2004; Pruessner et al., 1997) or using observation scales of withdrawal related affect or behavior (Buss et al., 2003; Hellhammer et al., 1997; Hessl et al., 2006). Only a few studies have addressed the relation between HPA-axis activation and social avoidance tendencies directly by means of controlled reaction time paradigms. Using such paradigm, Van Honk et al. (1998) found that the tendency to avoid social threat stimuli was associated with high basal cortisol levels. The latter authors measured the preconscious emotional response to social threat using a masked Stroop task, in which pictures of angry and neutral facial expressions were presented backwardly masked and subjects were instructed to color name the masks. In emotional Stroop tasks, attentional bias scores are calculated by subtracting the reaction times (RT) for neutral faces from those

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for angry faces. In these tasks, positive attentional bias scores (i.e. RT for angry faces is larger than RT for neutral faces) are taken to indicate vigilance, while negative attentional bias scores (i.e. RT for angry faces are shorter than RT for neutral faces) are thought to indicate avoidance (e.g. Putman et al., 2004; Van Honk et al., 1998, 2000; Mathews and MacLeod, 1994). The notions of vigilance and avoidance in the emotional Stroop task with respect to both masked and unmasked angry faces not only find support in light of correlational studies using personality questionnaires and hormone levels but is also causally supported by human studies applying hormone administration and repetitive transcranial magnetic stimulation (for reviews see: Van Honk and De Haan, 2001; Van Honk and Schutter, 2005). This task, thus, seems to provide a research paradigm for the study of human avoidance reactions and the way they are influenced by individual differences, such as differences in basal cortisol levels. However, the masked emotional Stroop task has not yet been applied in stress challenge studies that allow studying the effects of reactive cortisol levels. In the present study we applied the masked emotional Stroop test before and after a social stressor and investigated the effects of social stress and glucocorticoid stress-responsiveness on preconscious attention processing of social threat stimuli.

Although glucocorticoid stress-responsiveness has never been studied in relation to the attentional processing of *masked* social threat stimuli, it has been studied in relation to the processing of *unmasked* social threat stimuli in two recent investigations. Roelofs et al. (2005) used a manual approach–avoidance task during which subjects were instructed to evaluate the emotional valence of pictures presenting happy or angry facial expressions, by making either approaching (arm-flexion) or avoidant (arm extension) arm-movements. The manual responses were made in affect-congruent (i.e. happy face-approach; angry face-avoid) and affect-incongruent (happy face-avoid; angry face-approach) instruction conditions. Subjects were tested in a rest and social stress condition and stress was induced by the Trier social stress test (TSST: Kirschbaum et al., 1993) that is known to elicit significant cortisol responses in the majority of the subjects (Dickerson and Kemeny, 2004). Comparison of high and low cortisol-responders revealed that high responders showed larger congruency effects, involving faster avoidance reactions to angry faces in the rest condition. Most significantly, in the social stress condition the initial avoidance reactions of the high responders disappeared. Thus, subjects characterized by a high stress-responsiveness of the HPA-axis displayed relatively high avoidance tendencies in neutral circumstances but seemed to fail in their active avoidance tendencies during stress (Roelofs et al., 2005). Although this manual avoidance task offers a direct and controlled operationalization of avoidance tendencies (Rotteveel and Phaf, 2004) it remains difficult to determine whether stress and cortisol reactivity primarily affected processes involved in the response initiation, such as movement planning and preparation or also earlier processes such as attentional processing of the threat stimuli. In an attempt to shed light on this question we added an unmasked Stroop color-word task, presenting social threat, general threat and neutral words in the same experimental setup (Roelofs and Elzinga, 2005). The results again showed that the initially increased avoidance reactions of high cortisol-responders disappeared during stress and, whereas high responders became vigilant, the low responders turned avoidant during stress. Apparently it is not the cortisol response or the test context per see, but the interaction between these two factors that affected the subjects' motivated attention to social threat stimuli. These findings are in agreement with the results from animal (De Kloet et al., 1999; Okuda et al., 2004) and human (Abercrombie et al., 2006; Elzinga and Roelofs, 2005) studies, showing that cognitive changes during stress depend on an interplay between cortisol responses and the context in which they are elicited. However, the findings from unmasked Stroop test have been criticized for the fact that subjects may be able to override emotional Stroop effects (e.g. MacLeod and Hagan, 1992; Putman et al., 2004; Van den Hout et al., 1995; Van Honk et al., 1998; Williams et al., 1996). In contrast, subliminal Stroop tests using masked threat stimuli seem to provide for a more reliable index of motivated attention (Putman et al., 2004) that is less vulnerable to uncontrollable subject and task factors.

The purpose of the present study was to investigate whether the previously found interaction between social stress and glucocorticoid stress-responsiveness on avoidance behavior (Roelofs and Elzinga, 2005; Roelofs et al., 2005) would hold for the preconscious selective attention to social threat. To this end, healthy subjects were administered the masked emotional Stroop task mentioned earlier, applying angry and neutral facial expressions for stimuli. During the task, backwardly masked pictures of angry, neutral and happy faces were briefly presented. The happy faces were added to check for a possible attentional bias for emotional stimuli per se. Stress was again induced using the TSST and high and low cortisol-responders were compared with respect to their avoidance reactions in both a resting and a social stress condition.

Based on the previous findings (Roelofs and Elzinga, 2005; Roelofs et al., 2005) we expected to find a significant interaction between the test condition (rest versus stress) and the subject group (high versus low cortisol-responders) in such a way that the initially increased avoidance tendencies of high cortisol-responders would diminish under conditions of social stress.

2. Methods

2.1. Participants

We tested these hypotheses in a sample of twenty volunteers (18 females, 2 males) with a mean age of 22.1 years (S.D. = 4.2) who were originally recruited as a control group for a larger patient study addressing a different research question. Nine subjects used oral contraceptives and all except one females had registered the first day of the last menstruation allowing to calculate the current week of the menstrual cycle (week 1 ($n = 7$); week 2 ($n = 2$); week 3 ($n = 4$); week 4 ($n = 4$)).[1] The participants were recruited via advertisements and participated in the experiment for financial credit reasons. Exclusion criteria were: any psychiatric disorder on AXIS-I (DSM-IV, APA, 1994), any clinical significant medical disease, use of medication, and age <18 or >40. Partici-

[1] On average, the first two weeks of the menstrual cycle include the follicular phase followed by the ovulation and the last two weeks involve the luteal phase.

pants were instructed to minimize physical exercise during the hour preceding the experiment and not to take large meals, coffee, drinks with low pH or cigarettes, because these variables can affect cortisol levels. All participants had normal or correct-to-normal vision. The study was approved by the local ethics committee and all participants provided written informed consent.

2.2. Materials

2.2.1. Emotional Stroop task

Selective attention to happy and angry faces was assessed using a masked pictorial emotional Stroop task. Facial stimuli of 10 different individuals (5 males, 5 females) were taken from Ekman and Friesen's Pictures of Facial Affect (Ekman and Friesen, 1976), each displaying a neutral, a happy and an angry expression. The facial stimuli were presented for 14 ms (below the threshold for explicit visual awareness). Immediately after the stimulus presentation the pictures were replaced by a masking stimulus. The masking stimuli consisted of randomly cut, reassembled and re-photographed pictures of faces. At each trial, the stimulus and mask were presented in the same color (red, green or blue) and participants were instructed to vocalize this color. Upon vocal response initiation, the presentation of the masking stimulus was terminated. After a random inter-trial interval (ITI; 2–4 s) new trials started with a 750 ms lasting fixation point. A total of 30 happy, 30 angry and 30 neutral faces were presented in a random order with the restriction that the same color was never repeated more than twice consecutively. The dependent measures in the emotional Stroop task are attentional bias scores for emotional facial expressions (i.e. the mean individual color-naming latencies of angry (or happy) faces minus the individual mean color-naming latencies on neutral faces). A positive attentional bias score, indicating slower color-naming responses to emotional stimuli as compared to neutral stimuli, is interpreted as a vigilant response, whereas a negative attentional bias score, indicating faster color-naming responses to emotional stimuli as compared to neutral stimuli, is interpreted as an avoidant response (e.g. Putman et al., 2004; Van Honk et al., 1998, 2000; Mathews and MacLeod, 1994).

To maximize the quality of the voice key registration, the subjects were instructed to speak loud and clearly, to keep their mouth open during the task, to avoid smacking their lips or coughing before responding and to not correct their answer in case they had already started vocalizing an erroneous response. All instructions were practiced in a practice phase of nine stimulus presentations in which only masks were used (i.e. without facial stimuli).

To ascertain that subjects remained unaware of the variable of interest in the Stroop task, subliminal thresholds for the facial expressions were controlled for by an awareness check after the experiment. During this three-alternative, forced choice, emotional-neutral recognition procedure, a random set of 30 masked faces was shown to the subjects. In advance of the test the subjects were explicitly told that the set contained 10 happy, 10 neutral and 10 angry faces, and they were instructed to indicate (or guess), whether the presented picture contained a neutral, happy or angry expression by pushing the corresponding button.

2.2.2. The Trier social stress test

This psychological challenge test, which mainly consists of a free speech and a mental arithmetic task of 15 min duration, has been found repeatedly to induce significant endocrine and cardiovascular responses in the majority of the participants (Kirschbaum et al., 1993). The exact description of the procedure of the test is reported under the subheading 'procedure'.

2.2.3. Physiological and subjective measures

All physiological and subjective stress-measures were obtained at nine assessment points over a 200-min period, at respectively −60, 0, +20, +40, +60, +80, +100, +120 and +140 min with reference to the start of the stressor. All assessments were performed between 13.15 and 17.00 p.m.

Cortisol: Saliva samples were obtained using Salivette collection devices (Sarstedt, Rommelsdorf, Germany). Saliva samples were stored at −20 °C before assaying. Biochemical analysis of free cortisol in saliva was performed using a competitive electrochemiluminescence immunoassay (ECLIA, Elecsys 2010, Roche Diagnostics), as described elsewhere (Van Aken et al., 2003).

Heart rate (HR) was recorded continuously by an Ambulatory Monitoring System of the Vrije Universiteit Amsterdam (VU-AMS) version 3.6, a small battery powered device for ambulatory recording. It was measured via three Ag–AgCl disposable electrodes (ConMed), placed just above the sternum, at the left side of the chest, and at the bottom right side of the chest (cleaned with alcohol). For each participant, HR was post hoc averaged for 2 min starting from a marker given at each of the nine assessment points.

Systolic (SBP) and diastolic blood pressures (DBP) were measured from the non-dominant arm using an automatic blood pressure monitor (Omron R5-I) that could be initiated manually.

Finally, a subjective measure of anxiety, rated on a visual analogue scale, ranging from 0 to 10, was administered at each assessment point.

2.2.4. Psychological measures

Symptoms of anxiety and agoraphobia were measured using the corresponding sub-scales of the Dutch version (Arrindell and Ettema, 1986) of the Symptom Checklist (SCL-90, Derogatis, 1983).

2.3. Procedure

Participants arrived at the experimental room at 13.15 p.m., after which the VU-AMS device was connected and checked by the experimenter. After the first series of the physiological assessments, the emotional Stroop task was introduced. During this 8 min lasting task, participants were instructed to name as quickly as possible the color of the masking stimulus, which presentation was terminated after vocal response initiation. Task administration took place just before the second assessment (−15 min with reference to the onset of the stressor; see Fig. 1) and was preceded by a battery of additional cognitive tests, of which the results will be reported elsewhere. Subsequently, the experimenter introduced the TSST by telling the participants that they would be taking on the role of a job applicant (the job description was selected a priori, defining a position that would be challenging and relevant to the current situation of the participant). Participants were given 5 min to prepare a 5-min long, free speech to an audience of three individuals who were in another room waiting to interview them. They were told that the talk would be videotaped, that the psychologists were specially trained to monitor nonverbal behavior, that a voice frequency analysis of nonverbal behavior would be performed, and that the speech would be criticized on content and presentation style. They were also told that following the interview, they would be asked to complete an oral arithmetic challenge that would be judged on speed and accuracy. After this introduction, the experimenter left the room. Following the preparation time, the audience (three persons) entered the room and prominently switched on the camera and microphone. Participants were instructed to stand in front of a table with the audience sitting at the other side and the chairman who was seated in the center asked the participant to describe his/her qualifications for the job. A stopwatch lying prominently on the table was set to keep time. Participants were expected to utilize the entire 5 min for the speech as described by Kirschbaum et al. (1993). For the mental arithmetic task (5 min duration)

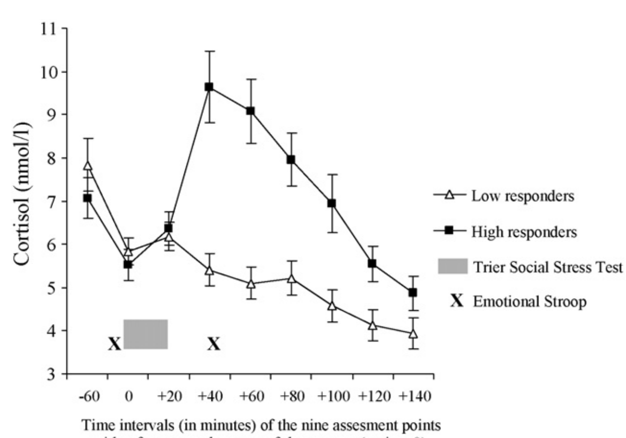

Fig. 1. Free salivary cortisol in nmol/l (mean ± S.E.M.) before, during and after TSST.

participants were instructed to serially subtract 13 from 1587. The audience responded to any mistakes by saying: ‘‘Incorrect, start from the top; subtract 13 from 1587’’. Immediately after the TSST, the audience called the experimenter back into the room and requested him to administer the cognitive tests including the emotional Stroop task again in their presence. In this way, the social stress context remained present during the second administration of the Stroop task (+40 min with reference to onset TSST). Subsequently the audience left the room and returned for a short debriefing after the last physiological assessment had taken place.

2.4. Statistical analyses

Reaction time outliers were filtered using a <150 and >1500 ms cut-off, and subsequent removal of all RTs exceeding 2.5 S.D. from the mean. For each participant, the remaining latencies (99.5%) for the correct responses were averaged over the facial expression types presented in each condition. The influence of stress induction on physiological and subjective stress measures, as well as the influence of stress and cortisol on the task performance, were tested using repeated measures analyses of variance (ANOVA rm). The relation between cortisol responses on the one hand and anxiety scores on the other hand were calculated using Pearson's correlations. All statistical analyses described employed a two-tailed alpha of 0.05 and effect sizes of significant results are reported using the partial eta squared (η^2).

3. Results

3.1. Physiological and subjective stress responses

3.1.1. Stress-induction

Separate one-way ANOVA's rm for the physiological and subjective stress measures (each measured at nine time points) showed significant increases on all stress measures over time: cortisol ($F(1, 19) = 19.13$, $p < 0.0001$, $\eta^2 = .50$); HR ($F(1, 19) = 10.44$, $p < 0.005$, $\eta^2 = .36$), SBP ($F(1, 19) = 43.84$, $p < 0.0001$, $\eta^2 = .69$); DBP ($F(1, 19) = 13.49$, $p < 0.005$, $\eta^2 = .42$) and subjectively experienced anxiety ($F(1, 19) = 58.41$, $p < 0.0001$, $\eta^2 = .49$). For all measures the mean rates assessed before stress induction (assessments 1–2) were significantly lower than the mean rates assessed after stress induction (assessments 3–9) (all $p < 0.001$), indicating that stress induction was successful.

3.1.2. Cortisol responses

The stress-related cortisol-response (CR) of each individual was computed by calculating the percentage increase from the individual minimum cortisol level before stress induction to the individual maximum after stress induction. The mean CR of the total group was 76.10% (standard error of mean (S.E.M.) = 35.04%). Subjects were post hoc (median split) allocated to a high ($n = 10$) and low ($n = 10$) responders group. The high responders had a mean CR of 144.93% (S.E.M. = 63.96) and differed significantly from the low responders (mean CR = 7.27%; S.E.M. = 6.43) in their cortisol responses ($F(1, 18) = 9.49$, $p < 0.01$, $\eta^2 = .35$) (see Fig. 1). The high and low responders did not differ with respect to HR ($F(1, 18) = 0.84$, $p = 0.52$), DBP ($F(1, 18) = 0.04$, $p = 0.84$) and subjectively experienced anxiety ($F(1, 18) = 2.08$, $p = 0.13$). However, the high responders showed a relative increase with respect to the SBP ($F(1, 18) = 4.47$, $p < 0.05$, $\eta^2 = .20$), compared to the low responders.

3.2. Behavioral results

3.2.1. Forced choice emotional-neutral recognition check

Chance performance in a three-alternative forced choice recognition check using 30 stimuli is 10 correct identifications per subject (33.33%). Of the total number of 600 trials, 199 were correct (=33.17%). Non-parametric tests showed that there was no significant deviation from the expected value (cut-point = 13) and that masking was successful ($n = 20$, $p = 0.70$).

3.2.2. Error rates

The error rates of the Stroop performance in the rest and stress conditions were 2.3% and 1.7%, respectively. There were no differential effects of facial expression, stress or cortisol response with respect to the error rates.

3.2.3. The effects of stress and CR on the Stroop performance

To investigate the effects of the social stress context and the cortisol responses (CR) on the selective attention to angry and neutral faces we conducted a two-way ANOVA rm for the attentional bias scores for angry faces (RT angry faces minus RT neutral faces) with condition (rest, stress) as within-subject factor and CR (high, low responders) as between-subject factor. There were no main-effects for condition ($F(1, 18) = 1.07$, $p = 0.31$) and CR ($F(1, 18) = 0.18$, $p = 0.68$) but there was a significant condition × CR interaction ($F(1, 18) = 5.55$, $p < 0.05$, $\eta^2 = .24$), showing opposite response patterns in high and low responders in rest and stress conditions (see Fig. 2). Compared to low responders, high responders showed a negative or avoidant attentional bias to threat (i.e. shorter latencies for angry than neutral faces) in the rest condition. Most importantly, although low responders became avoidant, the high responders became vigilant to social threat stimuli after stress induction. To test whether these effects were affected by gender, we excluded the two males from the analyses and found that the condition × CR interaction remained significant ($F(1, 16) = 5.32$, $p < 0.05$, $\eta^2 = .25$). Finally, we controlled for the use of Oral contraceptives and for the menstrual cycle (ranging from weeks 1 to 4 with reference to the onset of the menstruation). There was no significant main

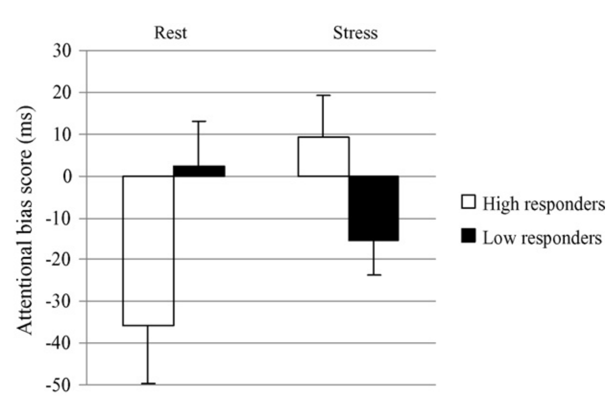

Fig. 2. Mean attentional bias scores for angry faces for (cortisol) high responders and low responders, tested in rest and stress conditions.

effect for menstrual cycle ($F(1, 13) = 0.25$, $p = 0.62$), but a significant main effect for Oral contraceptives ($F(1, 13) = 5.0$, $p < 0.05$, $\eta^2 = .27$) indicated a general RT slowing for non-users compared to users. Most importantly the condition $\times$ CR interaction remained significant after controlling for the effects of oral contraceptives and menstrual cycle ($F(1, 13) = 6.24$, $p < 0.05$, $\eta^2 = .32$). Univariate post hoc F-tests (also while controlling for oral contraceptives and menstrual cycle) for the attentional bias scores for angry faces showed that there were trends towards significant main effects for CR in both the rest ($F(1, 13) = 3.60$, $p = 0.08$, $\eta^2 = .22$) and the stress condition ($F(1, 13) = 4.18$, $p = 0.06$, $\eta^2 = .24$). There were no main and interaction effects of condition and CR for the attentional bias scores for happy faces (all $p > 0.11$).

3.2.4. Correlational analyses

The stress induced cortisol responses (maximum increase) were significantly correlated to the SCL90 agoraphobia subscale ($r = .76$, $p < 0.0001$) and showed a trend into the same direction for the SCL90 anxiety scale ($r = .46$, $p = 0.054$). In all reported correlations we controlled for the effects of oral contraceptives and menstrual cycle using partial correlations.

4. Discussion

The main purpose of this study was to investigate the effects of social stress and glucocorticoid stress responsiveness on the preconscious selective attention to social threat stimuli. The results showed that subjects with high and low glucocorticoid stress-responsiveness showed opposite reaction patterns to the social threat stimuli. In contrast to the low cortisol-responders, high responders showed a negative or avoidant attentional bias to threat (i.e. shorter latencies for angry than neutral faces) in the rest condition. Most importantly, although low responders became avoidant after stress induction, the high responders became vigilant to the social threat stimuli during stress. In other words, in the context of social stress the high responders showed a relative increase in selective attention for angry faces. Another important result was that these differential effects of stress and cortisol counted only for the attentional bias scores for angry faces and not for happy faces. These findings indicate that the effects of the social stress context and the cortisol stress-responsiveness were specific for context relevant (social threat) cues and not for unspecific emotional cues.

The diminished avoidance to threat in the high responders group during stress is in line with the results of two previous studies in which avoidance tendencies towards unmasked social threat cues were measured using a manual avoidance task (Roelofs et al., 2005) and an emotional Stroop color-word task (Roelofs and Elzinga, 2005), respectively. In the latter studies a significant interaction between the test condition (rest versus social stress) and group (high versus low cortisol-responders) also showed that high cortisol-responders displayed a decrease in avoidance tendencies towards the threat cues during stress. A new finding that emerges from the present study is that these interacting effects are already manifested on a preconscious level of attentional processing. The results from the awareness check in the present study confirmed that the subjects did not consciously perceive the stimuli. This makes it unlikely that they have exerted strategic effort to control attentional bias effects (e.g. MacLeod and Hagan, 1992; Putman et al., 2004; Van den Hout et al., 1995; Van Honk et al., 1998; Williams et al., 1996) and makes the findings less vulnerable to uncontrollable subject factors. This additional value of using a masked Stroop task is supported by the fact that masked compared to unmasked versions of the emotional Stroop task have yielded more consistent results (Putman et al., 2004) and by the finding that masked, as compared to unmasked emotional Stroop performance is more predictive of actual coping with stressful life events (MacLeod and Hagan, 1992).

The avoidant reactions of high responders in the rest condition correspond with the findings of a recent investigation applying the same masked Stroop task in patients with social anxiety disorder (Hermans et al., 2006). The patients were also tested in a non-stress condition and displayed avoidant reactions to the social threat cues as well. Interestingly, social anxiety disorder is also associated with elevated cortisol responses to social stress (e.g. Condren et al., 2002), which raises the hypothesis that glucocorticoid stress-responsiveness plays a role in the altered attentional processing in socially anxious subjects.

Previous studies have indicated that subjects who show relatively high cortisol responses in social stress tests tend to report lower self-esteem, more negative affect and higher social submissiveness than their low responding counterparts (Gruenewald et al., 2004; Pruessner et al., 1997). Also, we found increased glucocorticoid stress responsiveness to be associated with increased symptoms of anxiety and agoraphobia. In the light of these findings it is likely that our high responders group may have perceived the 'non-stress' test condition as more threatening than our low responders group. The fact that the high responders showed no increases on physiological and subjective stress measures in this rest condition may be due to the fact that these subjects tended to display more avoidance behavior. This was evidently shown by their Stroop performance in the rest condition but may also have been manifested in their general testing attitude in the rest condition. A previous study by Van Honk et al. (2000), for example, showed that individuals who pre-consciously directed their attention away from angry faces in the masked Stroop task, exhibited decreased post-task cortisol levels. These findings were interpreted as indicative of an adaptive response to social stress stimuli and it was speculated that these individuals may be best served by inhibited behavioral and physiological responses to avoid injury and energy loss (Flinn et al., 1998; Sapolsky, 1990). Whereas our high responders were able to show such an adaptive response in the rest condition, their initial avoidance reactions seemed to fail in the social stress condition. These diminished avoidance reactions during stress may be explained in several ways. In the first place the high responders may have had difficulty inhibiting the threatening stimuli that made part of the social stress context, resulting in an attentional bias towards the stress context and away from the emotional Stroop task. However, such general drop in selective attention for the task would likely have been accompanied by a general slowing or a drop in accuracy in task performance. Both were not the case. Also, the fact that the high responders directed relatively more attention to angry faces compared to neutral ones indicates that the facial stimuli presented in the Stroop test were still processed in the stress condition. A more plausible explanation for the failing avoidance and increased vigilance for social threat stimuli in the social stress context may be found in a behavioral inhibition that is comparable to so-called freezing responses observed in animals with elevated glucocorticoid stress-reactivity when they are exposed to stress. Research in animals has, for example, shown that high basal and reactive cortisol levels are associated with increased freezing and diminished active avoidance reactions during stress in primates (Kalin et al., 1998) and rats (Nunez et al., 1996). Freezing is regarded as an extreme form of behavioral inhibition and in primates it is suggested to be analogous to fearful responses frequently observed in intensely inhibited children (Kalin et al., 1991). Studies in these children also demonstrated extreme inhibition to be associated with increased levels of salivary cortisol (Kagan et al., 1988).

Finally, an alternative explanation of our findings that should be considered is the possibility that the relative increase in the high responders' attention to angry faces reflects an approach reaction towards threat evoked by the social stress context. However, this explanation is unlikely because such reaction is typical for subjects featured by high testosterone as opposed to cortisol levels (Van Honk et al., 1999). Cortisol and testosterone are associated with quite opposite motivations in situations of social threat. Generally, high levels of cortisol are related to socially avoidant, submissive behavior (Kagan et al., 1988; Sapolsky, 1990; Schulkin et al., 1998) whereas high levels of testosterone are related to socially dominant behavior (Mazur and Booth, 1998; Zuckerman, 1991). Moreover, the stress induced cortisol levels in the present study were positively related to self-report measures of anxiety and agoraphobia, which is also incompatible with an approach motivation.

To our knowledge the present study is the first to show the effects of stress and stress-induced cortisol on the preconscious selective attention to social threat stimuli, and suggests that the diminished avoidance reactions during stress are related to the glucocorticoid stress-responsiveness. However, some limitations should be considered when evaluating the findings. In the first place, although we did find a significant group (high, low responders) $\times$ condition (rest, social stress) interaction, the group sizes ($N = 10$) were relatively small. A strong point is that our results replicated the findings from two previous studies that applied the same study design, but used different avoidance tasks (Roelofs et al., 2005; Roelofs and Elzinga, 2005). Nevertheless, a replication of our findings with the masked emotional Stroop task in larger sample sizes would strengthen the results. Second, our sample primarily consisted of female subjects. Future studies are clearly needed to systematically examine gender differences. Another possible limitation is that the assessment of the menstrual cycle was not based on biochemical testing and depended on the accuracy with which subjects had registered the first day of the last menstruation.

Despite these limitations the present findings may have several important implications. First, the data reveal that the relation between high cortisol responses and diminished avoidance can already be observed at a preconscious level of attention processing. Second, a more general implication involves the importance of taking the glucocorticoid stress-responsiveness into account when studying avoidance behavior. That cortisol high responders and low responders may show quite opposite approach–avoidance reactions to social threat has been demonstrated several times now (see Roelofs and Elzinga, 2005; Roelofs et al., 2005). Finally, the data provide implications for future research. Testing participants featured by social anxiety such as patients with social phobia or post-traumatic stress is an important step to reveal the mechanisms by which stress-induced cortisol may affect avoidance behavior.

In sum, subjects with a high glucocorticoid stress-responsiveness (high responders) showed opposite reaction patterns to the social threat stimuli compared to subjects with low glucocorticoid stress responsiveness (low responders). In contrast to low responders, high responders showed a negative or avoidant attentional bias to threat in the rest condition. Most importantly, although low responders became avoidant during stress, high responders' initial avoidant reactions to the social threat stimuli disappeared in the context of social stress. These findings are in line with previous studies in both animals and humans, showing high glucocorticoid stress-responsiveness to be associated with diminished avoidance and prolonged freezing reactions in stressful situations. A new finding is that the relation between cortisol responses and failing avoidance already counts for the preconscious processing of threat. These findings may not only provide insight into fundamental processes mediating human avoidance reactions. They, moreover, offer a fruitful experimental model for the study of avoidance reactions in patients with anxiety disorders, such as social phobia and post-traumatic stress disorder.

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