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Short communication

Acute stress influences the discrimination of complex scenes and complex faces in young healthy men

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ABSTRACT

The stress-induced release of glucocorticoids has been demonstrated to influence hippocampal functions via the modulation of specific receptors. At the behavioral level stress is known to influence hippocampus dependent long-term memory. In recent years, studies have consistently associated the hippocampus with the non-mnemonic perception of scenes, while adjacent regions in the medial temporal lobe were associated with the perception of objects, and faces. So far it is not known whether and how stress influences non-mnemonic perceptual processes.

In a behavioral study, fifty male participants were subjected either to the stressful socially evaluated cold-pressor test or to a non-stressful control procedure, before they completed a visual discrimination task, comprising scenes and faces. The complexity of the face and scene stimuli was manipulated in easy and difficult conditions. A significant three way interaction between stress, stimulus type and complexity was found. Stressed participants tended to commit more errors in the complex scenes condition. For complex faces a descriptive tendency in the opposite direction (fewer errors under stress) was observed. As a result the difference between the number of errors for scenes and errors for faces was significantly larger in the stress group. These results indicate that, beyond the effects of stress on long-term memory, stress influences the discrimination of spatial information, especially when the perception is characterized by a high complexity.

1. Introduction

Due to a high density of mineralo- (MR) and glucocorticoid-receptors (GR), the hippocampus is highly susceptible to the influence of the stress-related release of the glucocorticoid cortisol. At the behavioral level, stress has been shown to influence hippocampus dependent declarative long-term memories (e.g., Schwabe et al., 2012). However, the impact of stress on non-mnemonic perceptual processes mediated by the hippocampus has not been tested so far.

In recent years, a substantial number of studies have accumulated that challenge the view that the medial temporal lobe is involved exclusively in declarative mnemonic processes. Areas within the medial temporal lobe (MTL) have repeatedly been linked to the high level visual perception of objects, scenes, and faces (Lech and Suchan, 2013). The involvement of the MTL in perceptual processes is assumed to be necessary especially when the stimuli are characterized by high feature ambiguity (Graham et al., 2010). Furthermore, a functional specialization of the hippocampus in the perception of scenes (Lee et al., 2012), and the perirhinal cortex (PrC) in the perception of faces and objects (Buckley and Gaffan, 2006; Collins and Olson, 2014), has been hypothesized. This functional dissociation is supported by patient studies, which indicate stimulus-specific functional impairments after damage to the hippocampus or the perirhinal and anterior enthorhinal cortices, respectively (Lee et al., 2006), and neuroimaging studies (Mundy et al., 2012).

The present study investigated the effects of stress in a visual discrimination task employing faces and scenes in a low complexity (easy) and a high complexity (difficult) condition (Lech and Suchan, 2014). While one group of participants underwent the socially evaluated cold-pressor test (SECPT; Schwabe et al., 2008), another group experienced a non-stressful control procedure prior

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to the discrimination task. We hypothesized that stress impairs the visual discrimination of scenes, especially when scenes are highly ambiguous, while the perception of faces remains unaffected.

2. Material and methods

2.1. Participants

The required sample size was determined using G*Power 3.1 (Faul et al., 2009), under the assumption of a medium-sized effect of stress on visual discrimination, which corresponds to Het et al. (2005) who found an average effect sizes of $d = -.49$ for the influence of cortisol on memory retrieval. Accordingly, the estimation of the sample size for a medium effect size of $f = .25$ (Cohen, 1969), an assumed correlation of within-subject factor of $\rho = .3$, and $\alpha = .05$, revealed a required sample size of 46 participants in order to achieve a power of $1 - \beta \geq .80$ to detect a significant two-way interaction comprising one between and one within-subject factor.

Fifty healthy right-handed males between 19 and 29 years of age ($M = 23.54$ years, SD = 2.85) participated after being screened for their general health status, with exclusion criteria such as a body mass index under 18 or above 29, the intake of medication, or a history of or current psychiatric and neurological disorders. Only participants who had not undergone the SECPT before were included.

Two participants reported that they had misunderstood the task instructions and were therefore excluded. Furthermore, two participants were identified as outliers in the baseline cortisol levels, which exceeded two standard deviations above the mean. All participants gave written informed consent and were paid 12€ each at the end of the experiment. The experiment was approved by the ethics committee of the Faculty of Psychology at the Ruhr University Bochum.

2.2. Perceptual task and procedure

Experimental sessions took place between 10 am and 1 pm in order to control for the diurnal cycle of cortisol. Participants were randomly assigned to a stress ($N = 25$) or a control group ($N = 21$). After giving written consent, the stress group underwent the socially evaluated cold-pressor test (SECPT; Schwabe et al., 2008), while the control group was subjected to a non-stressful control procedure. During the SECPT, participants had to immerse their right hand into ice water (0–2 °C) for up to three minutes while they were filmed by a video camera and observed and instructed by a reserved female experimenter. The control procedure comprised the immersion of the right hand in warm water (35–37 °C) without an experimenter and without being filmed. Subsequently, participants rated the subjective level of difficulty involved in keeping the hand immersed, as well as the subjective discomfort, pain, and stress they felt during the treatment, using an 11-point-scale ranging from 0 (none at all) to 100 (very much).

Twenty minutes after the beginning of the experimental manipulation, the participants completed a visual oddity task (Fig. 1A; Buckley et al., 2001) with four conditions, each comprising one of two stimulus types (faces and scenes) combined with one of two task complexities (easy and difficult). Each condition was performed in a separate block consisting of 36 trials each. In order to minimize mnemonic demands of the task, three stimuli were presented simultaneously in each trial. Furthermore, all presented stimuli were trial unique. Participants had to indicate by a button press which of the presented pictures was the odd one out. The order of stimulus type (faces vs. scenes) was randomized, while easy conditions were always followed by difficult conditions. A fixation cross was presented at the beginning of each trial, followed by the presentation of either three faces or three scenes for 4000 ms, irrespective of the response. The duration of the intertrial interval was jittered between 1000 and 3000 ms. No feedback was given to the participants.

Pictures of faces showed unfamiliar human Caucasian faces (both male and female, aged 20–40, not wearing glasses). Face stimuli in the difficult condition were created by rotating faces along the vertical axis between −60° and 60° in steps of 30°, while faces were shown in frontal view in the easy condition. For the difficult scene condition, one and the same photograph was used to create three different pictures, each showing a selected section of the original photograph, which overlapped either by 75% or by 90%. The picture with the least amount of overlap was defined as the target stimulus. In both easy conditions, two identical and one different picture were shown, the latter of which was considered the target stimulus (cf. Lech and Suchan, 2014).

Saliva samples were collected one minute before (BL) and one (+1), twenty (+20), and forty (+40) minutes after treatment to assess salivary cortisol concentrations. Blood pressure was measured with the Dinamap system (Critikon, Tampa, FL) before, during, and after treatment. Salivettes (Sarstedt, Nümbrecht, Germany) were used to collect saliva. A cortisol luminescence immunoassay (IBL, Hamburg, Germany) was used to analyze cortisol concentrations. Inter- and intra-assay coefficients of variance were below 10%.

2.3. Data analysis

In order to analyze the participants' subjective ratings of the treatment, two-tailed t-tests were applied. Cortisol data, as well as blood pressure and heart rate, were analyzed by means of a Group (stress group vs. control group) by Time (BL, +1, +20, and +40; pre, during, and after, respectively) mixed-design ANOVA. Behavioral data were analyzed with respect to the error rate, which has been utilized to identify impairments in discrimination tasks after MTL lesions (Graham et al., 2010). A mixed-design ANOVA was applied with the between-subjects factor Group (stress vs. control) and the within-subjects factors Stimulus Type (faces vs. scenes) and Complexity (easy vs. difficult). In the case of a violation to the assumption of sphericity, Greenhouse-Geisser correction was applied and corrected degrees of freedom (df), corrected p-values, and ε-values are reported. Significant interactions were resolved by two-tailed t-tests. In case of inhomogeneous variances, Welch's correction of degrees of freedom was applied. Multiple post-hoc comparisons were conducted on Bonferroni-corrected α_{Bon}-levels. Confidence intervals (CI) of the means were calculated with respect to $1 - \alpha_{Bon}$ confidence levels. Partial η^2 are reported as estimations of effect sizes, while η^2-values of .01 are interpreted as small effects, $\eta^2 = .06$ as medium, and $\eta^2 = .14$ as large effects sizes (Cohen, 1969).

3. Results

3.1. Subjective and physiological stress reaction

Analyses of subjective and physiological data revealed a successful stress induction by the SECPT. The stress group rated the treatment as significantly more unpleasant, more stressful, more painful, and more difficult (all $t < -5.8$, all $p < .001$, all $\eta^2 > .44$; Table 1) than the control group. Group by Time interactions were detected for both systolic and diastolic blood pressure (systolic: $F(2,88) = 34.926$, $p < .001$, $\eta^2 = .443$; diastolic: $F(1.76,77.52) = 34.677$; $p < .001$, $\eta^2 = .441$, $\varepsilon = .881$), as well as for heart rates ($F(1.62,71.23) = 3.645$, $p = .040$, $\eta^2 = .077$, $\varepsilon = .809$). A Group by Time interaction for cortisol confirmed different cortisol concentrations in both groups over time ($F(1.75, 75.12) = 9.636$, $p < .001$, $\eta^2 = .183$, $\varepsilon = .582$; Fig. 1B). Resolution of this interaction

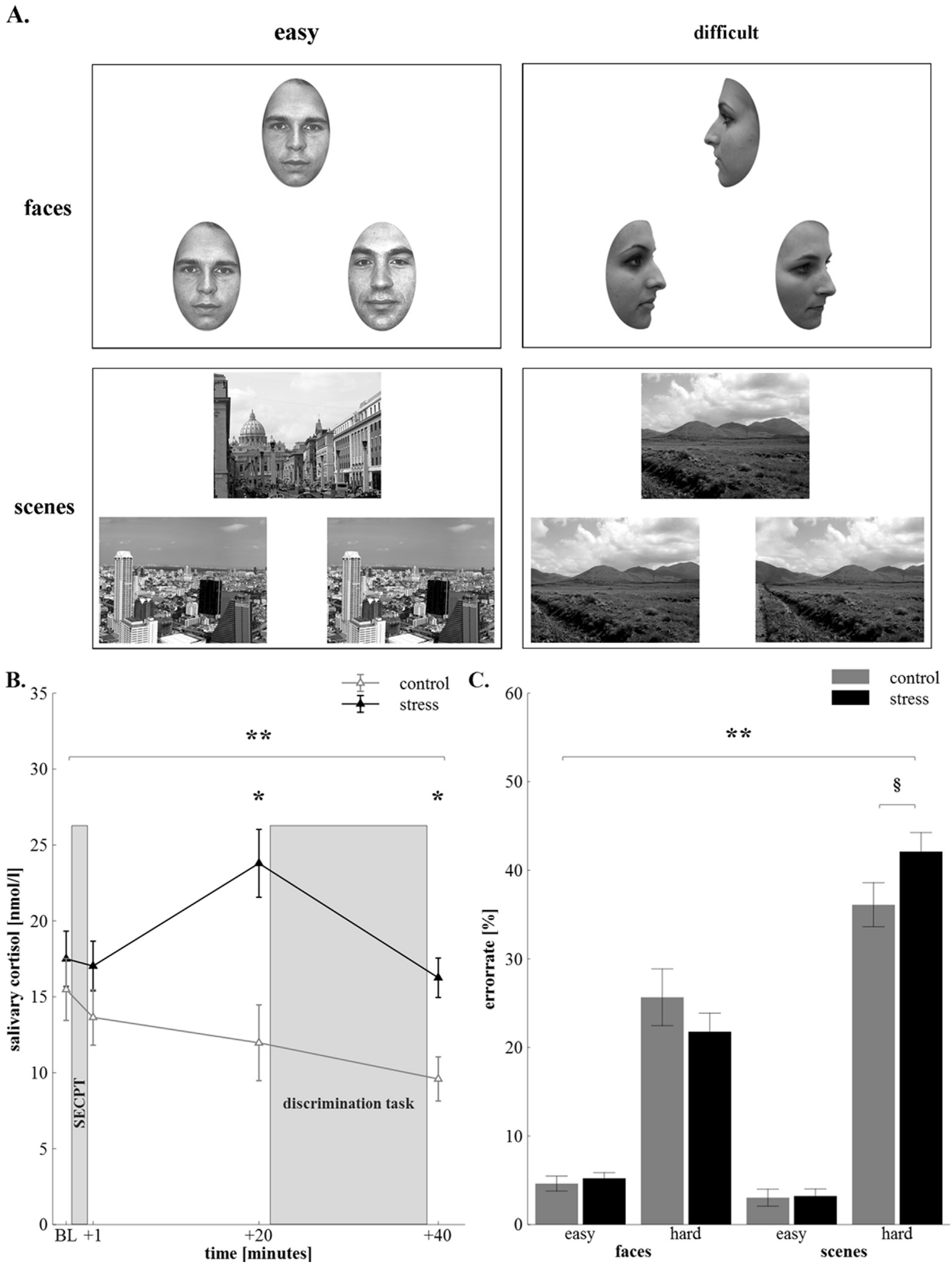

Fig. 1. (A) The paradigm utilizes faces and scenes in an easy and a difficult condition. Three stimuli were presented simultaneously in each trial. (B) Saliva cortisol concentrations of the control and the stress group over the course of the experiment are depicted. The time points of the saliva samples are reported with respect to the beginning of the experimental manipulation. **Group by Time interaction ($p < .001$), *Post-hoc t-tests between groups ($p < .001$). (C) Error rates of the control and the stress group are depicted for faces and scenes for the easy and the difficult conditions separately. **Group by Stimulus Type by Complexity interaction ($p = .020$), §Group difference on a trend level ($p = .073$) in post-hoc t-tests. All data represent the mean ± SEM.

Table 1
Subjective ratings, duration of hand immersion, systolic, and diastolic blood pressure in the stress and control group.

	Control	Stress
Subjective ratings		
Unpleasantness	3.81 ± 1.76	50.80 ± 5.03**
Stressfulness	1.90 ± 1.48	32.40 ± 5.04**
Painfulness	0.00 ± 0.00	55.20 ± 4.84**
Difficulty	0.48 ± 0.48	46.40 ± 6.00**
Duration of hand immersion [s]	180.00 ± 0.00	158.52 ± 9.28*
Systolic blood pressure [mmHg]		
Pre-treatment	126.43 ± 2.50	126.56 ± 2.29
During treatment	124.71 ± 2.64	141.37 ± 2.42**
Post-treatment	118.84 ± 2.25	126.32 ± 2.06**
Diastolic blood pressure [mmHg]		
Pre-treatment	67.86 ± 1.73	68.16 ± 1.58
During treatment	68.84 ± 1.86	82.83 ± 1.71**
Post-treatment	65.40 ± 1.97	67.48 ± 1.81

* $p < .05$.
** $p < .01$.

revealed a significant elevation of cortisol levels in the stress group compared to the control group 20 and 40 min after treatment (both $t > -3.6$, both $p < .001$, both $\eta^2 > .355$). The control group immersed their hands significantly longer than the stress group ($t(44) = 2.314$, $p = .030$, $\eta^2 = .113$).

3.2. Behavioral data

Scenes caused generally higher error rates than faces (main effect Stimulus Type: $F(1,44) = 31.155$, $p < .001$, $\eta^2 = .444$), and higher error rates were detected in difficult conditions than in easy conditions (main effect Complexity: $F(1,44) = 391.630$, $p < .001$, $\eta^2 = .899$; Fig. 1C). Stress did not induce a general decline in performance (main effect Group: $p > .6$).

A significant Stimulus Type by Group interaction emerged ($F(1,44) = 4.263$, $p = .045$, $\eta^2 = .088$). Moreover, this interaction was qualified by a significant Stimulus Type by Complexity by Group interaction ($F(1,44) = 5.859$, $p = .020$, $\eta^2 = .118$). The resolution of this three-way interaction revealed a significantly larger difference between difficult scenes and difficult faces in the stress group compared to the control group ($t(41.81) = -2.319$, $p = .025$, $\eta^2 = .107$, CI = [−18.48, −1.28]), while the difference between easy scenes and easy faces did not differ between both groups ($t(28.88) = .313$, $p = .757$, $\eta^2 = .002$, CI = [−2.29, 3.11]). The higher error rates of the stress group in the difficult scenes compared to the control group revealed a non-significant trend ($t(41.63) = 1.829$, $p = .073$, $\eta^2 = .074$, CI = [−1.63, 13.63]). In the difficult face condition, stress was descriptively associated with an enhanced performance compared to the control group ($t(35.46) = 1.014$, $p = .317$, $\eta^2 = .028$, CI = [−5.08, 12.85]). In the easy face and easy scenes conditions no difference between groups was detectable (all $t < .6$, all $\eta^2 < .01$).

4. Discussion

The current study examined the influence of stress on the visual perception of scenes and faces. Participants were engaged in a visual discrimination task after one group had been subjected to the stressful SECPT, while another group had undergone a non-stressful control procedure. A significant three way interaction between stress, stimulus type and complexity was found. Stressed participants tended to commit more errors in the complex scenes condition. For complex faces a descriptive tendency in the opposite direction (fewer errors under stress) was observed. As a result the difference between the number of errors for scenes and errors for faces was significantly larger in the stress group.

These findings go beyond well-established stress-related impairments of hippocampal-dependent long-term memory retrieval (Wolf, 2009) in that they suggest an impairment in the discrimination of spatial information, while the discrimination of faces remains spared. The results are consistent with the idea that the involvement of MTL regions in perception and memory is determined by the stimulus type, with the hippocampus crucial for the perception of scenes and the PrC important for faces (Graham et al., 2010). Given that the hippocampus is characterized by a high density of GRs and MRs, we assume that the stress effect on the perception of scenes is caused by elevated cortisol concentrations in the stress group.

Recent fMRI-studies demonstrated activation of the hippocampus during the visual discrimination of scenes, while both PrC and hippocampus activations were detected during face discrimination (Barense et al., 2010; Lech and Suchan, 2014). These results confirmed that the hippocampus is involved in the discrimination of scenes when the scenes are ambiguous, whereas the PrC is recruited in face perception.

On the basis of the current behavioral study, conclusions about the neural underpinnings of the observed stress effects on the perception of scenes cannot be drawn. Future neuroimaging studies should elucidate whether the influence of stress on the perception of faces and scenes is mediated by alterations in hippocampal activity. Indirect evidence from previous stress studies point towards reduced hippocampal activity in the aftermath of acute stress. For example, exposure to the SECPT was associated with reduced hippocampal activity in a probabilistic classification task (Schwabe and Wolf, 2012).

Previous results have demonstrated alterations of face processing after psychological stress, due to an increased sensitivity of the amygdala in response to face stimuli, irrespective of the emotional expression. The descriptively enhanced performance caused by stress was therefore perhaps caused by an altered responsiveness of the amygdala or early sensory areas to faces (van Marle et al., 2009).

In the current study performance for complex scenes was poorer than performance for complex faces. We therefore cannot rule out the alternative explanation that it is the difficulty rather than the content (faces vs. scenes) which underlies the selective effect of stress on complex scenes observed in the present experiment.

In this experiment only men were tested. Conclusions about the presence or absence of similar stress effects on face and scene perception in women can therefore not be drawn. Testing took place in the morning, a time of day associated with higher and more variable cortisol concentrations. Nevertheless we were able to show a robust cortisol increase in response to the SECPT which was accompanied by changes in perceptual discrimination. Our findings are in line previous work on memory retrieval illustrating that acute stress impaired hippocampal based episodic memory retrieval to a similar degree in the morning and the afternoon (Smeets, 2011). These finding suggest that it is the increase rather than the absolute cortisol concentrations that determine the impact of the stressor on cognition.

In sum, the current study presents initial evidence for a stress-induced impairment in the discrimination of complex scenes. The findings suggest that non-mnemonic cognitive processes mediated by the hippocampus are influenced by acute stress.

Contributors

MP, RKL, BS & OTW designed the study, wrote the protocol, and conducted literature searches. RKL & BS developed and implemented the perception task. MP & JS conducted the study. MP, JS, AMD & OTW analyzed the data. MP, JS and OTW wrote the first draft of the manuscript. All authors contributed to and have approved the final manuscript.

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Conflict of interest

The authors declare that they have no conflict of interest regarding this manuscript.

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