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Research report

Stress improves task processing efficiency in dual-tasks

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HIGHLIGHTS

- Dual-task performance becomes better under stress.
- Improvements emerge as a consequence of increased processing efficiency.
- Improvements are predictable on the basis of salivary cortisol concentrations.

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ABSTRACT

Psychological stress has attracted much interest as a potential modulator of response control processes. However, especially in dual-task situations, the effect of psychological stress is less understood. In the current study we investigated these effects. "Thirty six" healthy young male participants were exposed to stress applying the socially evaluated cold pressor task (SECPT) or a control condition. Afterwards they participated in a psychological refractory period (PRP) paradigm comprising two tasks (a "tone task" and a "letter task"). With the PRP task, four different stimulus onset asynchronies (SOA) were realized separating the tone from the letter task. The results show that stress improves task processing efficiency in dual-tasks. Stressed participants showed a reduced PRP effect (i.e., shorter response times), which was especially prominent in the short SOAs conditions (16 and 133 ms). The analysis of the response times suggests that stress increases dual-tasking performance by modulating the efficiency to process the different tasks and not because 'cognitive flexibility' and switching between task components at the bottleneck is altered. Increases in processing efficiency in dual-tasks were predictable by means of individual salivary cortisol levels.

1. Introduction

Response selection and control processes play a pivotal role in daily life and have been examined in relation to a plenty of factors. Out of these, psychological stress has attracted interest as a potential modulator of response control processes, but the results are contradictive: some results suggest that stress improves selective attention processes, necessary for efficient unfolding of response control functions [1] and it has also been shown that stress facilitates performance in task-switching and stroop paradigms [2]. However, with respect to task switching other findings account for opposite effects, i.e., task-switching is impaired under stress [3,4]. These results are well in line with findings showing that stress increases shielding of action goals and thereby leads to reduced cognitive flexibility [5].

However, only recently, the effects of stress have been examined in relation to multi- and dual-task performance. While stress-induced increases in task shielding are evident in single-tasks, it has been shown that acute stress leads to reduced shielding of task goals, when one task is prioritized over the other in dual-task situations [6]. However, current evidence [6] on the effects of stress on dual-task processing focused on processes related to a priorization of the first task. Hence, little is known about the effects of stress on the succeeding task, when both tasks are of equal importance. However, this is of importance, since especially task 2 (T2) processing is subject to processing restrictions when the two tasks in two different streams of information are processed simultaneously or quasi-simultaneously [7]. This phenomenon is known as the psychological refractory period (PRP) effect [8,9]. The psychological refractory period (PRP) paradigm is a classical paradigm to examine dual-task interference [10,11]. In this paradigm two tasks are presented in close succession and participants are asked to respond as quickly as possible to each task. The typical finding is that responses on the second task are slower when the second task was presented shortly after the first task (=PRP effect) [8,9]. With increasing time (stimulus onset asynchrony, SOA) between the

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tasks, the interruption of T2 processing (i.e., the PRP) that becomes smaller [10]. Even though the precise nature of this processing limitation is still open to debate [10–13] it is widely agreed that the limitation is due to processing limitations at the response selection stage [14]. As flexible behavioural adaption have long been suggested to promote dual-tasking performance [8,15] it may be hypothesized that stress impairs dual-tasking abilities due to its known negative effect on cognitive flexibility [3,5].

However, psychological stress has been suggested to affect catecholaminergic signalling [16] and dopamine D2 receptor related neural transmission in particular [e.g., 17,18]. Response control processes, as examined using the PRP, have been shown to depend on dopaminergic neural transmission and fronto-striatal networks [e.g., 19–21]. Very recent results indicate that dual-task performance is rendered more efficient under conditions, where punishment feedback is provided in case of slow reaction times [22]. Yildiz et al. [22] showed that reaction times on the second task are faster, when punishment is provided in case of slow reactions. Opposed to this they showed that rewards were not able to speed up responses on the second task, but rather led to a slowing of responses. As reward and punishments are mediated via different dopaminergic receptors, these results suggest that dual-tasking is differentially modulated by dopaminergic subsystems.

The effects of punishments on dual-tasking are of relevance for the modulator "stress". Punishments have been shown to be mediated via the dopamine D2 receptor system and hence a receptor system that plays an important role in the mediation of stress effects on cognitive functions [16–18]. Against this background it is therefore more likely that stress increases dual-tasking performance, i.e., leads to faster reaction times on task two in short SOAs. However, the recent study by Yildiz et al. [22] suggest that modulatory effects were only evident in an experimental condition, where the task order was unpredictable. In the current study we therefore examine the effect of stress in two blocks, where task order is either predictable or unpredictable. If the effects of stress are similar to the effects of punishments [cf. 22] we expect that stress modulated reaction times in short SOAs in the unpredictable task block, only.

2. Materials and methods

2.1. Participants

A sample of 36 healthy, right-handed male participants were recruited and randomly assigned to the experimental ($N = 18$) and the control group ($N = 18$). Participants had normal or corrected-to-normal vision. The participants received course credits or financial compensation for their participation. The study was approved by the Ethics committee of the Ruhr-University of Bochum. Each subject gave written informed consent in addition that experiments were carried out in accordance with the Declaration of Helsinki. Smokers were excluded from participation because nicotine changes the neuroendocrine stress response [23].

2.2. Induction and quantification of stress

Participants in the stress condition ($N = 18$) were exposed to the socially evaluated cold pressor test (SECPT) [cf. 24]. Briefly, they put their left or right foot for 3 min (or until they could no longer tolerate it) into ice water (0–2 °C). Deviating from the usual SECPT protocol we did not use the hand in order to avoid that manual response times (RTs) are unaffected. During this phase, they were videotaped and monitored by an unfamiliar person. Participants in the control condition put their foot into warm water (35–37 °C) for 3 min. They were neither videotaped nor monitored by an unfamiliar person. To assess whether the stress induction by the SECPT was successful, subjective stress ratings, blood pressure, and salivary cortisol were measured: Immediately after the SECPT or control condition, subjects indicated on a scale from 0 ("not at all") to 100 ("very much") how stressful, painful, and unpleasant they had experienced the previous situation. Blood pressure and pulse frequency was measured 5 min before, during, and again for 5, 20 and 50 min after the stress or control condition with the cuff placed on the left upper arm. Participants collected saliva samples before as well as 5, 20, and 50 min after the SECPT or control condition with a Salivette collection device (Sarstedt, Nuembrecht, Germany). Saliva samples were kept at −20 °C until analysis. Free cortisol concentrations were measured using an immunoassay (IBL, Hamburg, Germany). Interassay and intra-assay coefficients of variance were below 10%.

2.3. Experimental paradigm

We used a PRP paradigm that is identical to the paradigm used in a previous study by our group investigating the effects of rewards on dual-task performance [22]. The paradigm comprised of two tasks: a "tone task" (task 1) and a "letter task" (task 2). In the "letter task", white letters ("H" or "O"; 1.8° × 2.3° visual angle) are presented on a dark blue screen and subjects had to indicate, whether an "H", or and "O" was presented on the screen (task 2). In the "tone task", sine wave tones were presented with a pitch of 300 or 900 Hz (task 1). Each stimulus lasted for 200 ms. Each trial consists of both of these tasks and begins with the presentation of a central fixation cross at the centre of the screen. After one second the stimulus S1 (tone) was presented, followed by the presentation of the S2 stimulus (letter) in a predefined stimulus onset asynchrony (SOA) of either 16, 133, 500 or 1000 ms. Participants responded with their left hands to the tone stimulus and with their right hands to the letter stimulus and subjects were instructed to place equal emphasis on both tasks. For the tone stimulus, the button underlying the left middle finger had to be pressed for low tones (300 Hz) and the button underlying the left index finger had to be pressed for the high tone (900 Hz). For the letters, subjects pressed with their right index finger on an "H" and with their right middle finger for an "O" [cf. 13]. Participants had to respond as quickly and accurately as possible to each stimulus and were told to place equal emphasis on both tasks.

Subjects were required to respond to the second stimulus within 2000 ms. Trials exceeding this deadline were defined as misses. In case of misses the next trial was started within 1500 ms jittered between 500 and 2500 ms. For trials, in which responses were given within 2000 ms, the next trial was started after a response-stimulus interval (RSI) jittering between 1000 and 4000 ms. In one block of the PRP task the letter stimulus always follows the tone stimulus. In another experimental block there was no fixed, but a random order of the T1 and the T2 stimulus; i.e., it was impossible to predict, which of the two tasks comes first, and which comes second. There were two fixed and two random blocks presented in counterbalanced order across participants (ABAB or BABA). Each block consisted of 320 trials, summing to 1280 trials for the whole experiment.

For the RT data analysis across SOAs the data was screened for trials in which the difference in RT between task 1 and task 2 was 100 ms or less, to account for possible effects of 'response grouping'. Subjects were requested to respond first to the first stimulus appearing (irrespective of the task). This means that in the random task order RT1 comprises responses to tones and letters. The same is true for T2. For the statistical analysis of the data, data was not grouped with respect to the modality of the stimulus, but for its occurrence (i.e., first or second stimulus). Hence, data was pooled across the different modalities in the random block. In the statistical analysis the modality of the T1 and T2 stimulus is therefore discarded in the random block. This procedure is reasonable, since the PRP effect is determined by the temporal order and proximity of stimuli.

2.4. Statistical analysis

Behavioural data were analyzed using mixed effects ANOVAs. Greenhouse–Geisser correction was applied where necessary and post hoc tests were Bonferroni-corrected. Before testing, Kolmogorov–Smirnov tests were carried to test normal distribution. All variables included were normal distributed ($p > .4$).

3. Results

3.1. Physiological effects of stress induction

Salivary cortisol levels were analyzed in a mixed effects ANOVA with time point of salivary cortisol probe sampling at within-subject factor and "stress" as between-subject factor. The ANOVA revealed an interaction "time point × stress" ($F(3, 105) = 5.2$; $p = .002$; $\eta^2 = .931$). Subsequent bonferroni-corrected post hoc t-tests revealed that there was no difference in salivary cortisol concentrations prior to stress induction ($t(35) = 0.26$; $p > .45$). At all other time points, the salivary cortisol levels were higher in the stressed group, compared to the control group (all $t(35) = -2.14$; $p = .014$) (refer Fig. 1A) ($p < .001$).

As peripheral physiological measures systolic and diastolic blood pressure (refer Fig. 1B) as well as pulse frequency (refer Fig. 1C) was analyzed. The mixed effects ANOVA on the systolic blood pressure there was an interaction "time point × stress" ($F(3, 140) = 3.01$; $p = .20$; $\eta^2 = .079$). The same was found for the diastolic blood pressure ($F(3, 140) = 12.26$; $p < .001$; $\eta^2 = .259$). For the diastolic blood pressure, bonferroni-corrected post hoc t-tests revealed differences between the stressed and the control group at the time point of stressing ($t(35) = -2.43$; $p = .01$), but not at the