

# Behavioral Neuroscience

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Online First Publication, April 1, 2013. doi: 10.1037/a0032334

### CITATION

Pabst, S., Schoofs, D., Pawlikowski, M., Brand, M., & Wolf, O. T. (2013, April 1). Paradoxical Effects of Stress and an Executive Task on Decisions Under Risk. *Behavioral Neuroscience*. Advance online publication. doi: 10.1037/a0032334

# Paradoxical Effects of Stress and an Executive Task on Decisions Under Risk

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In everyday life, decisions are often made under stress and while being occupied with multiple tasks. It has recently been shown that acute stress impairs decision making under risk. Performing a parallel executive task also caused riskier decision making. To investigate the effects of a combination of these two factors on decision making, we conducted a large ( $N = 126$ ) experimental study with a  $2 \times 2$  design (stress vs. no stress and parallel task vs. no parallel task). Stress was induced using the Trier Social Stress Test (TSST) and controls underwent the placebo TSST. Salivary samples were collected to assess cortisol and alpha amylase concentrations as markers of the two stress response systems. Decision making was measured using the Game of Dice Task (GDT). A 2-back task served as parallel executive task. Our results revealed a significant interaction between stress and the parallel executive task. In line with our earlier findings, acute stress and a parallel executive task individually tended to impair decision making under risk, manifested by more high risky than low risky choices. Interestingly, stressed participants in the parallel-task condition (GDT plus 2-back) showed similar decision-making behavior as nonstressed single-task participants. Regression analyses revealed executive functions to moderate stress effects on decisions under risk. Reasons for these paradoxical findings are discussed with respect to stress-evoked cognitive alterations that may benefit decision making under risk, if an executive task is performed simultaneously.

*Keywords:* decision making under risk, acute stress, parallel executive task, executive functions, salivary cortisol

In everyday life, it has become a frequent occurrence that decisions are made while being occupied with multiple tasks. Additionally, decisions are often to be made under the influence of stress, due to the abundance of tasks to manage or exterior factors. It is therefore important to understand how decisions are made

under stressful circumstances while performing more than one task at a time. Decision making can be differentiated into situations of ambiguity (e.g., stock market) and those under conditions of risk (e.g., lottery; Brand, Labudda, & Markowitsch, 2006). In contrast to ambiguous situations in which the outcome is neither calculable nor known, decisions under risk offer a set of explicit and stable rules. These enable the decision maker not to rely on hunches and received feedback only, but provide the opportunity to estimate possible consequences (Starcke & Brand, 2012).

Dual-process theories picture two systems supporting decision-making processes (Epstein, Pacini, Denes-Raj, & Heier, 1996; Kahneman, 2003). System 1 is known as the intuitive–experiential system, which acts fast, parallel, effortless, but also with emotion. With this system, because of its use of frugal and fast accessible heuristics often used in situations of uncertainty, decisions of ambiguity are associated. System 2 is named the rational–analytical system. It acts slow, serial, and effortful, but also controlled and neutral. In consequence of its analytical nature, System 2 demands active executive processes like cognitive flexibility, planning, and strategy formation. Decisions under conditions of risk ought to be processed by System 2 to benefit from its calculative and rational behavior, necessary for an accurate estimation of possible consequences and long-term advantageous choices. Although such a subdivision of decision processes has a long-

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This work was supported by the German Research Foundation (DFG; WO773/11-1; BR2894/6-1). We thank Annika Deckers and Andrea Gördes for assistance in data collection.

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standing history, a clear differentiation between emotional and rational decisions cannot be made. Studies with ambiguous and risky decision-making tasks have, for example, shown that ambiguous decisions may also involve executive processes (Brand, Recknor, Grabenhorst, & Bechara, 2007), and risky decisions may be influenced by experiencing emotional feedback (Brand, 2008).

Yet considering the parallel and effortless nature of System 1, an ambiguous decision-making task (e.g., the well-known Iowa Gambling task [IGT]; Bechara, Tranel, & Damasio, 2000) processed by this system may not be impaired by a parallel executive task, as decision making should mainly depend on feedback processing instead of analytical reasoning. A study using the IGT supports this hypothesis, as participants who performed an executive task simultaneously performed similar in the decision-making task as participants who performed the IGT solely (Turnbull, Evans, Bunce, Carzolio, & O'Connor, 2005). Vice versa, if both tasks are claiming resources of System 2, a parallel task is thought to impair decision making. This hypothesis was investigated by combining the Game of Dice Task (GDT; Brand et al., 2005), a computerized decision-making task of chance with explicit and stable rules of gains and losses, and an n-back working memory task (Starcke, Pawlikowski, Wolf, Altstotter-Gleich, & Brand, 2011). Results showed a deterioration of GDT performance with increasing difficulty of the n-back task, indicating that an additional task requiring executive functions impairs decision making under risk.

Research has shown the involvement of prefrontal cortical structures in executive functions, that is, the ventromedial and, especially, the dorsolateral prefrontal cortices (vmPFC and dlPFC; Jonides et al., 1997; Kahnt, Heinzle, Park, & Haynes, 2011; Lie, Specht, Marshall, & Fink, 2006). As System 2 of dual-process theories demands executive processes, it is assumed that these cortical structures play a vital role in decision making under risk and thus for performance in the GDT (Brand et al., 2006). Patients with deficits in executive tasks associated with dlPFC functioning showed impaired decision making under risk (Brand et al., 2004, 2005; Manes et al., 2002; Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999). In addition, difficulties in decision making under risk were found in healthy participants with relatively low executive functions (Brand, Laier, Pawlikowski, & Markowitsch, 2009; Schiebener, Zamarian, Delazer, & Brand, 2011).

Much research has been conducted to investigate the effect of emotions on decision making (Bechara, 2004; Bechara, Damasio, & Damasio, 2000; de Vries, Holland, & Witteman, 2008; Dunn, Dalgleish, & Lawrence, 2006; Pfister & Bohm, 1992; Starcke & Brand, 2012). In the literature, a differentiation has been suggested for emotions and their relation to a decision (Bechara & Damasio, 2005). Intrinsic emotions may be beneficial for a decision-making situation (Zeelenberg & Pieters, 2006). On the other hand, extrinsic emotions, which do not stand in a relationship to a decision-making situation (Zeelenberg, Nelissen, Breugelmans, & Pieters, 2008), may negatively affect the decision-making process (Bechara & Damasio, 2005). Being emotionally and physically challenging, acute stress can be understood as a composition of such extrinsic emotions, if the stressor per se is not connected to the decision-making process. Stress is perceived as negative if individuals believe that available resources are inadequate in order to meet or master external challenges (Lazarus & Folkman, 1986). This belief may be accompanied by feelings of insecurity, anger, anxiety, or shame (Dickerson & Kemeny, 2004). Being confronted

with a stressor typically evokes a neuroendocrine stress response characterized by an activation of the two major physiological response pathways. First, the activity of the sympathetic nervous system (SNS) increases immediately after stress onset, leading to an increase of catecholamines. The resulting high levels of catecholamines impair prefrontal activity (Arnsten, 2009). The second pathway, the hypothalamic-pituitary-adrenal (HPA) axis, constitutes a somewhat slower stress response, conceptualized as the second defense wave (Elenkov, Wilder, Chrousos, & Vizi, 2000; Kirschbaum & Hellhammer, 2000). Associated with the activation of the HPA axis is the enhanced release of the glucocorticoid cortisol (de Kloet, Joels, & Holsboer, 2005; McEwen, 2006), which reaches its peak about 20 to 40 min after stress onset (Dickerson & Kemeny, 2004).

Neuroimaging studies have reported heterogeneous results as to how stress affects prefrontal regions and thereby executive functions. Stress induction in the scanner resulted in decreased activation in the orbitofrontal cortex (Pruessner et al., 2008) and an increased activation in the medial and dlPFC (Dedovic, D'Aguiar, & Pruessner, 2009; Pruessner, Champagne, Meaney, & Dagher, 2004). Other studies, which have investigated these brain regions, found an increase in ventral activation and a decrease in dlPFC activation when participants performed a working memory task after stress induction (Oei et al., 2012; Qin, Hermans, van Marle, Luo, & Fernandez, 2009). Opposing response patterns have been observed as well (Weerda, Muehlhan, Wolf, & Thiel, 2010). Concomitant with stress-induced alteration in prefrontal activity, decision making may be negatively affected due to the dependency of advantageous decisions on well-functioning executive processes. In previous studies, stress was associated with inflexibility (Kassam, Koslov, & Mendes, 2009) and nonsystematic scanning of alternatives (Keinan, 1987). In addition, stress led to more disadvantageous choices represented by riskier decision making in the GDT (Starcke, Wolf, Markowitsch, & Brand, 2008). For a review on decision making under stress, see Starcke and Brand (2012). However, it has to be acknowledged that the literature regarding stress and PFC functioning is rather heterogeneous and evidence for enhanced PFC functioning (e.g., inhibition, flexibility, goal-shielding) after stress has been reported (Kofman, Meiran, Greenberg, Balas, & Cohen, 2006; Plessow, Fischer, Kirschbaum, & Goschke, 2011).

As illustrated earlier, decisions under risk have previously been shown by our group to be negatively affected by an additional parallel executive task (Starcke et al., 2011) and acute stress (Starcke et al., 2008), respectively. Yet the question remains whether a combination of both of these factors leads to an even more substantial impairment in an additive or even interactive fashion (Starcke et al., 2008, 2011). Thus, we investigated whether acute stress and a parallel executive task combined would lead to riskier decision making in the GDT paradigm. We hypothesized that a combination of both factors would intensify the impairing effect on decision making under risk due to an increased demand of executive processes and the additional factor of stress altering prefrontal activity. An additional goal was to replicate our previous findings within the same study and with the usage of a more powerful stressor (Starcke et al., 2008, 2011). A  $2 \times 2$  between-subject design was used, resulting in two control groups and two stress groups, one performing the GDT only and the other performing the GDT with a parallel executive n-back task.

## Method

### Participants

The entire sample consisted of 126 students between the ages of 18 and 33 years,  $M = 23.95$ ,  $SD = 2.64$ . Participants were randomly assigned to either the stress condition (64 participants, 34 female) or the control condition (62 participants, 30 female). Further, each group was divided into a single-task group performing only the GDT and a parallel-task group performing the GDT and a parallel n-back task (see description of the tasks in the following sections). All participants were interviewed by telephone beforehand to assure they met study requirements. Exclusion criteria were obesity (body mass index [BMI] in  $\text{kg/m}^2 > 30$ ), smoking, acute or chronic illness, a history of neurological or psychiatric disease, drug abuse, or shift work. Neither psychology students of a higher semester nor potential participants acquainted with the stressor or the decision-making task were included. Women did not use hormonal contraceptives of any kind, were not pregnant, and were not tested during menses. In addition, participants were instructed not to become engaged in exhausting physical activities and to abstain from alcohol 24 hr before testing. Further, they were asked to get up at least 2 hr before testing and not to eat or drink 1 hr before testing. All testing was conducted between 10:00 a.m. and 12:30 p.m. In the control parallel-task group, data of two male participants had to be excluded from any further analyses due to technical failure and subsequent missing values. All participants gave written informed consent and received €25 for their participation. The study was approved by the ethics committee of the German Psychological Association (DGPs).

### Stress Induction

We used the TSST (Kirschbaum, Pirke, & Hellhammer, 1993) to induce acute psychosocial stress. The TSST has been shown to be an effective instrument to increase the activity of the HPA axis and the SNS (Dickerson & Kemeny, 2004). While being videotaped, participants were asked to perform a free speech and a mental arithmetic task after preparation time (5 min each) in front of a committee consisting of two individuals (a woman and a man) acting reserved and distant. As a nonstressful control condition, we used the placebo-TSST (p-TSST; Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009), which lacks the socioevaluative components of the TSST. Participants gave a speech alone in the test room, were not videotaped, and performed an easier mental arithmetic task.

### Neuroendocrine Stress Markers

We took salivary samples while the different tasks were performed to measure cortisol as an indicator for HPA axis activity, and salivary alpha-amylase (sAA) as an indirect marker of SNS activity (Kirschbaum & Hellhammer, 1994; Nater & Rohleder, 2009). Salivette collection devices (Sarstedt; Nuembrecht, Germany) were used to collect saliva at five time points (1 min before and 1, 10, 20, and 60 min after cessation of either treatment; i.e., TSST or p-TSST). Samples were analyzed at the laboratory of Professor Kirschbaum, Department of Biopsychology, Technical

University Dresden, Germany. For cortisol, an immunoassay (IBL, Hamburg, Germany) was used. For sAA analysis, a quantitative enzyme-kinetic method was used (Rohleder & Nater, 2009; van Stegeren, Rohleder, Everaerd, & Wolf, 2006). Inter- and intra-assay variations were below 10%.

### Measurement of Affect

To assess stress effects on positive and negative affect, we used the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants were asked to rate 10 items for positive affect and 10 items for negative affect on a 5-point scale, with a range from 1 (*very slightly or not at all*) to 5 (*extremely*). Using the averaged rating a score for positive and negative affect was computed. A higher score indicated higher positive or negative affect, respectively.

### Psychological Distress

In order to measure general psychological distress before stress was induced, we used the Brief Symptom Inventory (BSI; Franke, 2000), a short version of the symptom checklist 90 (SCL-90-R; Franke, 1995). The inventory consists of 53 items, measuring distress on nine different subscales (e.g., depression, anxiety) on a 5-point scale, within a range of 0 (*not at all*) to 4 (*extremely*). Participants were asked to answer how often they felt confronted with different symptoms within the last 7 days. The Global Severity Index (GSI) was calculated, which measures general psychological distress. A higher score indicated more psychological distress.

### Ability of Dividing Attention

Before exposure to the TSST or p-TSST, respectively, we measured the ability to divide attention to simultaneously ongoing processes, as part of executive functions, using the Test of Attentional Performance (TAP; Zimmermann & Fimm, 2009) subtest Divided Attention (TAP-DA). This task consists of a visual and auditory task. Participants were placed in front of a computer using one key and were instructed that in a specific area on the screen, represented by a  $4 \times 4$  rectangle of dots, a varying number of crosses would appear. They were asked to press the key if four of these crosses built a square. At the same time participants heard high and low tones in sequence over headphones. Again, they were asked to press the key if the same tone occurred twice in a row. Participants were allowed to use their dominant hand to respond and were instructed to respond as fast as possible. We used the total score of missed target stimuli for further analyses. This score is established to be the crucial marker of task performance (Zimmermann & Fimm, 2009). Thus, a lower score indicated better performance.

### Decision Making and Parallel Task

To assess decision making under risk, we used the original GDT (Brand et al., 2005) for the single-task conditions and a modified GDT version including a parallel working memory task, requiring executive control, for the parallel-task conditions (Starcke et al., 2011).



The GDT is a computerized gambling task and simulates decision making under explicit and stable rules. In addition, feedback is given about the outcome of a decision previously made. Participants were asked to pursue the goal of maximizing their fictitious starting capital of €1,000. They were instructed that in each one of 18 trials, a single die would be thrown. Participants had to decide before each trial whether they chose a single number or a combination of two, three, or four numbers. All alternatives were permanently shown on the screen. Money is won if the thrown number matches the single number or one of the numbers among the chosen combination; otherwise, money is lost. Associated with these combinations are explicit and stable gains and losses and concomitant winning–losing probabilities. By choosing a single number, €1,000 are gained/lost (winning probability 1 out of 6). A €500 gain/loss is received for the choice of a combination of two numbers (winning probability 2 out of 6), a €200 gain/loss for three numbers (winning probability 3 out of 6), and a €100 gain/loss for four numbers (winning probability 4 out of 6). With focus on probabilities, the alternatives can be grouped into higher risk (disadvantageous) and lower risk (advantageous). The single-number and two-number combinations are understood to be disadvantageous choices, as the winning probability is below 34%. The combinations of three or four numbers are advantageous, as the winning probability is 50% and higher. The sequence of a trial is to choose one of the altogether 14 given alternatives (grouped into the described four categories), after which the die is thrown. Feedback is provided about any gain or loss, the current capital, and the number of trials left. Combinations are chosen using the right hand for mouse navigation, selecting the desired alternative. Individual performance was measured by calculation of a net score, subtracting disadvantageous from advantageous choices; a higher score indicated better performance (Brand et al., 2005, 2009; Starcke et al., 2008).

In the GDT plus parallel-task groups, we used the 2-back paradigm as a parallel working memory task, which was performed simultaneously to the GDT (Starcke et al., 2011). Both tasks were shown on the computer screen, with the 2-back task being integrated into the GDT and presented in the lower left corner. In the 2-back task, numbers from 1 to 9 are displayed in a randomized and successive order. Participants had to remember if the current number present on the screen was the same as the number presented two trials before. Responses were given using the index and middle fingers of the left hand. Numbers were presented for 500 ms with an interstimulus interval of 2,750 ms, leaving participants a time limit of 500 ms to respond. Feedback was provided by a green check mark for correct responses and a red cross for false responses. The probability of target stimuli (same stimulus as two trials before) was 33% (Schoofs, Preuss, & Wolf, 2008). The total number of trials depended on the time participants took for GDT completion. Two-back task performance was computed as the percentage of correct responses.

## Design and Procedure

At arrival, participants answered a demographic questionnaire followed by the TAP-DA and the BSI. At baseline measurements, the PANAS was administered and the first salivary sample was taken right before TSST or p-TSST performance, respectively. After the treatment, the second salivary sample was taken and the

PANAS was filled out again. The decision-making task was performed at the expected cortisol peak right after the third (+10 min) sample. Participants collected the fourth (+20 min) salivary sample right after task completion. Until the fifth salivary sample was taken 60 min after treatment, participants performed additional tasks not addressed in the current article.

## Statistical Analysis

All statistical analyses were conducted using SPSS 20.0. For group comparison concerning sex, Pearson's  $\chi^2$  test was used. One-way ANOVAs were used to compare groups for age, psychological distress, and executive functions. A univariate analysis of covariance (ANCOVA) was computed for comparison of GDT performance. Moderated regression analyses (hierarchical regression) were performed to determine whether GDT performance was moderated by acute stress, a parallel task, the ability to divide attention as part of executive functions, or any of their interactions. An ANOVA with repeated measurement was used to determine alterations in cortisol and sAA concentration as well as changes in positive and negative affect. To follow up possible main effects and interactions of GDT performance, cortisol and sAA concentrations at different measurement time points, simple effect tests were conducted. For 2-back comparisons, a multivariate ANOVA was computed. Relationships were examined computing Pearson's correlations. For all analyses, two-tailed tests were performed with  $p$  set to .05.

## Results

The four groups did not differ concerning sex, age in years ( $M = 23.97$ ,  $SD = 2.66$ ), psychological distress as measured by the BSI ( $M = 0.45$ ,  $SD = 0.28$ ), or executive functions as measured by the TAP-DA ( $M = 1.78$ ,  $SD = 2.05$ ), all  $ps > .537$ .

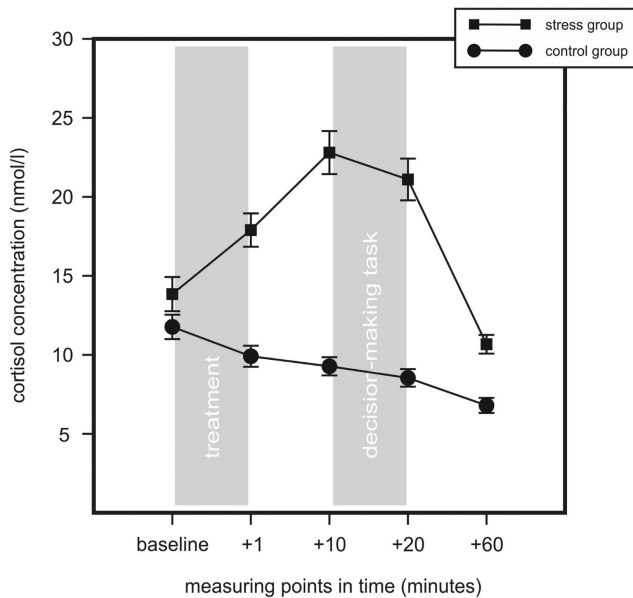
## Cortisol and sAA Responses

As normal distribution for cortisol and sAA values was not given, all values were thus logarithmized. Results indicated higher cortisol concentrations in the stress compared with the control group. Within the stress group, we found a descriptive trend of a lower reaction in cortisol in women compared with men, but no significant three-way interaction. We performed a 2 (stress)  $\times$  2 (sex)  $\times$  5 (measurement time points) repeated measurement ANOVA for cortisol and sAA, respectively. For within-subject effects, the ANOVA showed a significant interaction of Time  $\times$  Stress,  $F(2.16, 241.90) = 56.53$ ,  $p < .001$ ,  $\eta^2 = .33$ . Simple effect tests revealed significant differences for the stress and control group at sampling points 1, 10, 20, and 60 min after stress induction, all  $F_s(1, 114) > 37.44$ , all  $ps < .001$ , all  $\eta^2_s > .19$ . Results are shown in Figure 1.

For sAA, a significant effect for the interaction Time  $\times$  Stress,  $F(2.45, 274.26) = 7.98$ ,  $p < .001$ ,  $\eta^2 = .07$ , was found. Simple effect tests showed a higher sAA activity in stressed participants 1 min after stress induction compared with the control group,  $F(1, 112) = 8.53$ ,  $p = .004$ ,  $\eta^2 = .07$ . Results are shown in Figure 2.

## Positive and Negative Affect

Two separate ANOVAs with repeated measurement were computed for positive and negative affect, respectively, with the



**Figure 1.** Results of the salivary cortisol measures of male and female participants in the stress group compared with the control group during the course of the experiment. Stress increased cortisol concentrations in the stress group, but not in the control group. Data represent means and standard errors. Raw (untransformed) values are presented in this figure for illustrative purposes. For statistical analysis, log transformed data was used (see Results section).

within-subject factor of time (pre- vs. posttreatment) and the between-subject factors of stress and sex. Neither a significant change of positive affect over time nor a Time  $\times$  Stress, Time  $\times$  Sex, or Time  $\times$  Stress  $\times$  Sex interaction could be found.

For negative affect, an effect for the interaction Time  $\times$  Stress,  $F(1, 120) = 34.32, p < .001, \eta^2 = .22$ , was detected. Stressed participants showed an increase in negative affect over time (before TSST:  $M = 1.24, SD = 0.27$ ; after TSST:  $M = 1.81, SD = 0.76$ ), but controls did not (before p-TSST:  $M = 1.35, SD = 0.54$ ; after p-TSST:  $M = 1.30, SD = 0.50$ ). An influence of the factor of sex did not occur.

### Decision-Making Performance

A univariate ANCOVA was performed with GDT net score as the dependent variable, and stress, parallel task, and sex as between-subject factors. Past research has indicated a relationship between psychological distress (e.g., trait anxiety, depression) and decision-making behavior (Maner et al., 2007; Mitte, 2007; Werner, Duschek, & Schandry, 2009). Moreover, an initial analysis with the current data set revealed a correlation between GDT performance and psychological distress,  $r = -.201, p = .025$ , indicating a negative effect of general distress on GDT performance. In order to remove the impact of global distress on the current data set, the BSI-GSI score was used a covariate.

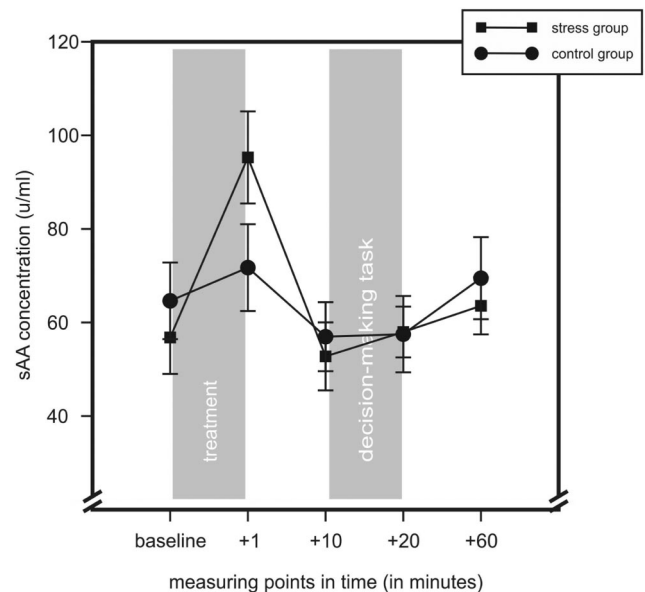
Results did not reveal a main effect of stress,  $F(1, 124) = 0.01, p = .94, \eta^2 < .01$ , parallel task,  $F(1, 124) = 0.07, p = .79, \eta^2 < .01$ , or sex,  $F(1, 124) = 0.08, p = .78, \eta^2 < .01$ . Yet a significant interaction between stress and parallel task,  $F(1, 124) = 4.08, p = .046, \eta^2 = .03$ , was found. Results are illustrated in Figure 3. None

of the interactions, including the factor of sex, reached significance, all  $ps > .68$ .

The following response pattern caused the Stress  $\times$  Treatment interaction: Stressed participants performing the GDT only, and nonstressed participants performing the GDT and the parallel 2-back task, showed riskier decision making than control participants performing the GDT alone. However, stressed participants performing the GDT and 2-back task simultaneously showed similar decision-making behavior as controls performing the GDT only. Simple effect tests showed no significant differences between the four groups (control: single vs. parallel task,  $F(1, 120) = 1.86, p = .173, \eta^2 = .02$ ; stress: single vs. parallel task,  $F(1, 120) = 1.53, p = .218, \eta^2 = .01$ ; single task: stress vs. control,  $F(1, 120) = 1.66, p = .200, \eta^2 = .01$ ; parallel task: stress vs. control,  $F(1, 120) = 1.74, p = .189, \eta^2 = .01$ ). Thus, the factors stress and parallel task interacted significantly, whereas none of the single comparisons between the four groups reached significance.

### Parallel Task Performance

To compare 2-back task performance within the parallel-task condition, a multivariate ANOVA was conducted with percentage of correct responses and number of trials as the dependent variables and stress and sex as between-subject factors. Results showed no significant effect for correct responses (stress group:  $M = 62.67, SD = 16.07$ ; control group:  $M = 65.30, SD = 14.31$ ) or number of trials (stress group:  $M = 76.44, SD = 12.08$ ; control group:  $M = 72.97, SD = 11.22$ ) for the factors of stress and sex or their interactions, all  $ps > .10$ . This indicates that both groups achieved a similar working memory performance. As each trial of



**Figure 2.** Results of the salivary alpha amylase (sAA) measures of male and female participants in the stress group compared with the control group during the course of the experiment. Stress increased sAA concentrations. Data represent means and standard errors. Raw (untransformed) values are presented in this figure for illustrative purposes. For statistical analysis, log transformed data was used (see Results section).

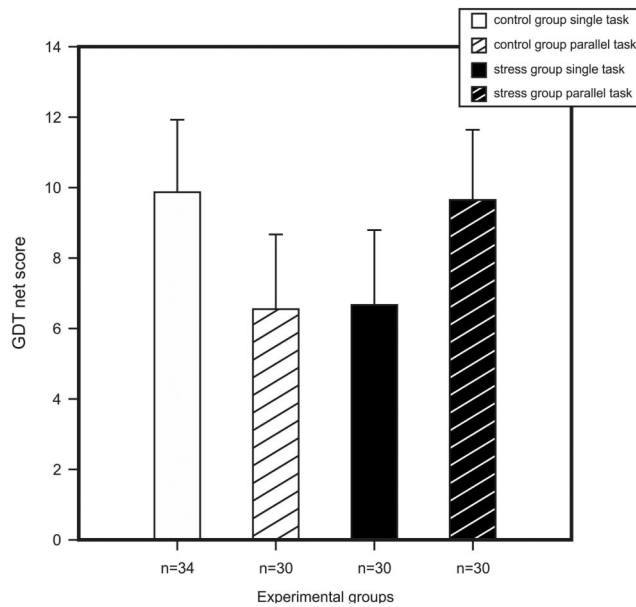


Figure 3. Mean net score (number of advantageous choices minus number of disadvantageous choices) representing Game of Dice Task (GDT) performance for the four groups stress vs. control and single task vs. parallel task. Statistical analysis using an ANCOVA revealed a significant interaction between stress and parallel task performance. Stress or parallel task alone tended to impair decision-making performance. In contrast, stress combined with a parallel task lead to a performance indistinguishable from the nonstressed control group. Data represent means over participants with standard errors.

the 2-back task consists of a fixed sequence, the total number of trials indicated that task performance speed between stress and control group did not differ. Sex also did not influence 2-back task performance.

### Moderation of GDT Performance

To analyze whether the effects of stress and a parallel task on GDT performance is moderated by the ability to divide attention (DA-ability) as part of executive functions, we calculated a moderated, hierarchical regression analysis, with GDT net score as a dependent variable and stress, parallel task, and TAP-DA missed targets as predictor variables. In the first step, the three predictor variables—stress, parallel task, and TAP-DA—together explained 4% of the variance,  $R^2 = .04$ ,  $F(3, 120) = 1.49$ ,  $p = .22$ . In a second step, interaction effects were calculated for Stress  $\times$  Parallel Task, Stress  $\times$  TAP-DA, and Parallel Task  $\times$  TAP-DA (all variables centralized; Cohen, Cohen, West, & Aiken, 2003). The two-way interactions together showed a nonsignificant trend of an increase of variance explanation,  $\Delta R^2 = .06$ ,  $F(3, 117) = 2.54$ ,  $p = .06$ . In a third step, the interaction Stress  $\times$  Parallel Task  $\times$  TAP-DA was calculated and included into the model. This three-way interaction did not reach significance and variance explanation did not change,  $\Delta R^2 = .004$ ,  $F(1, 116) = 0.55$ ,  $p = .46$ . Overall, 10% of variance of GDT performance (GDT net score) was explained by stress, a parallel task, DA-ability, and the two-way and three-way interactions of these three predictor variables,

$R^2 = .099$ ,  $F(7, 116) = 1.82$ ,  $p = .089$ . Further statistical values for the main effects and interactions can be found in Table 1.

For GDT performance (GDT net score), we attained a negative slope for the simple regression line representing “stress.” This was significantly different from zero,  $t = 1.94$ ,  $p = .05$ , for participants of the group “GDT single task” when TAP-DA had a value of one standard deviation above the mean, indicating poorer GDT performance under stress if participants had a lower DA-ability. For participants of the group “GDT parallel task” with a TAP-DA value of one standard deviation below the mean, a positive slope showed a descriptive increase, but was not significantly different from zero,  $t = 1.35$ ,  $p = .18$ . The two remaining slopes did not reach significance (group “GDT single task”: TAP-DA value one standard deviation below the mean,  $t = 0.45$ ,  $p = .65$ ; group “GDT parallel task”: TAP-DA value one standard deviation above the mean,  $t = 0.44$ ,  $p = .66$ ). This indicates a better GDT performance without stress, and a worsening under acute stress, for participants with a lower DA-ability working on the GDT only. In contrast, participants with a higher DA-ability working on the GDT and 2-back task perform less risky under acute stress than without. Acute stress does not alter GDT performance in participants with a higher DA-ability performing the GDT only and participants with a lower DA-ability performing the GDT and 2-back task. Results are illustrated in Figure 4.

GDT performance was neither correlated with nor moderated by HPA axis or SNS activity. Overall, as well as within group correlations and moderated regression, analyses did not show any significant relationships for salivary cortisol and sAA, respectively, all  $ps > .36$ .

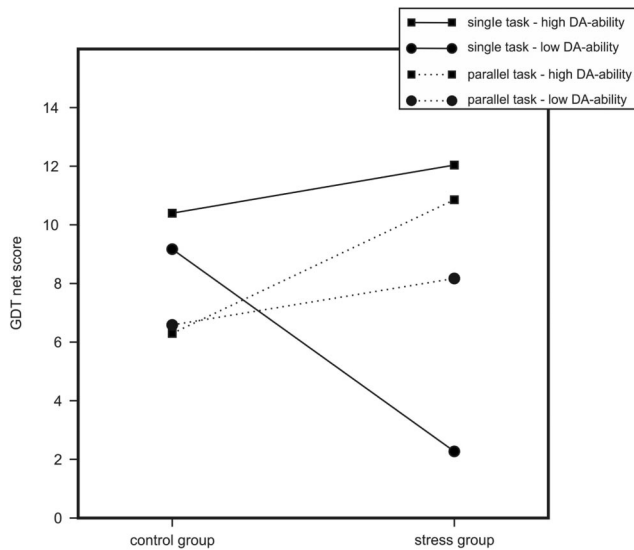
### Discussion

In this study, we investigated how acute stress and a parallel executive task alone or in combination influence decision making under risk. Stressed participants showed a rapid increase in sAA activity. Additionally, elevated salivary cortisol was found after the treatment and throughout the remaining session, reaching its peak at 10 min after the TSST. In accordance with the typical rapid SNS response and a somewhat delayed activation of the HPA axis, stress was successfully induced. This conclusion is further sup-

Table 1  
Moderator Analyses With GDT Net Score as Dependent Variable and the Predictors Stress, Parallel Task, and TAP-DA Missed Targets

Predictors/Interactions	$\beta$	$t$	$p$	$\Delta R^2$
Main effects				
Stress	.012	.132	.895	
PT	-.025	-.286	.776	
TAP-DA	-.174	-1.91	.059	
Two-way interactions				
Stress $\times$ PT	.147	1.66	.100	.06
Stress $\times$ TAP-DA	-.144	-1.59	.115	
PT $\times$ TAP-DA	.107	1.18	.240	
Three-way interaction				
Stress $\times$ PT $\times$ TAP-DA	.067	.742	.460	<.01

Note. GDT = Game of Dice Task; PT = parallel task; TAP-DA = Test of Attentional Performance – subtest Divided Attention total score missed target stimuli.



**Figure 4.** Results of the moderated regression analysis investigating the relationship between the ability to divide attention to simultaneous ongoing processes (DA-ability) as part of executive functions (measured by the Test of Attentional Performance – subtest Divided Attention; see Method section), acute stress, and a parallel task on decision making under risk. Statistical values can be found in the Results section. The figure illustrates that participants with a higher DA-ability of the single-task group performed similar under acute stress compared with the control group. Participants with a lower DA-ability of the single-task group performed worse under stress, but performed well in the control group. Participants with a higher DA-ability of the parallel task group indicated an improvement of performance under stress compared with the control group. Participants with a lower DA-ability of the parallel task group performed similar under acute stress compared with the control group.

ported by the observed increase in negative affect in the stress group.

We reported a significant orthogonal two-way interaction between stress and parallel task for decision making, as measured by the GDT paradigm. Stressed participants of the single-task group made riskier decisions compared with nonstressed controls. Among nonstressed participants, those performing the GDT and a parallel 2-back task made riskier decisions than participants of the single-task condition. Interestingly, acute stress and an additional executive task did not lead to an increased impairing effect on GDT performance. In contrast, stressed participants performing the GDT and 2-back task showed similar decision making as controls of the single-task condition. Thus, rather than acting in an additive, or even synergistic, fashion, the effects of stress and a secondary task cancelled each other out. It must be noted that the significant orthogonal interaction caused only numerical trend differences between the groups, yet these differences are in accord with previous results from our groups (Starcke et al., 2008, 2011).

The finding that nonstressed participants of the parallel-task group made riskier decisions than nonstressed single-task participants is consistent with previous findings of our group (Starcke et al., 2011). As both the GDT and 2-back task demand executive processes and resources of the same cognitive system (as argued in the Introduction), they may interfere (Evans, 2003; Kahneman, 2003). Imaging studies suggest the involvement of the lateral PFC

as responsible for task order coordination and task interference resolution (Duncan, 2001; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006). An additional executive task may lead to a higher work load of the lateral PFC, and thus impaired decision making, as found in previous investigations and also in the current study.

The result that stressed participants perform poorer in decision-making tasks compared with nonstressed participants is also consistent with past research (for a review, see Starcke & Brand, 2012), although a clear variance of effect sizes between results can be identified. In accordance with our present results, a previous study of our groups has shown riskier decision making in the GDT after an anticipatory speech stressor (Starcke et al., 2008). It has to be acknowledged, however, that the size of the effects observed by Starcke and colleagues were larger than those observed in our current study.

The origins of a stress-induced behavioral shift concerning decision making can be found in cognitive and/or emotional alterations, as caused by neuroendocrinological processes. Stress-evoked high concentrations of catecholamines such as noradrenalin and dopamine, and an increased concentration of the glucocorticoid cortisol, may alter and/or impair functioning of neural correlates of decision making, such as the dlPFC, vmPFC, anterior cingulate cortex, and striatum (Arnsten, 2009; Assadi, Yucel, & Pantelis, 2009; Dedovic et al., 2009; Ramos & Arnsten, 2007; Vijayraghavan, Wang, Birnbaum, Williams, & Arnsten, 2007; Wickens, Horvitz, Costa, & Killcross, 2007). Because of such a large neuronal realm being affected, behavioral shifts can be made manifest in a variety of ways. Studies reported stress effects such as decreased task performance, nonsystematic scanning of alternatives (Keinan, 1987), and slower learning of task contingencies (Preston, Buchanan, Stansfield, & Bechara, 2007). The stress-evoked collaboration of SNS activity and cortisol has been shown to shift goal-directed to habitual behavior (Schwabe, Hoffken, Tegenthoff, & Wolf, 2011; Schwabe, Tegenthoff, Hoffken, & Wolf, 2010), and may result in cognitive inflexibility (Plessow et al., 2011) and a shift to a resource-saving mode to spare cognitive capacities (Plessow, Schade, Kirschbaum, & Fischer, 2012). The consequences may be an intuitive and automatic, rather than rational and calculative, behavior, which leads to disadvantageous decision making under conditions of explicit and stable rules (Brand et al., 2009).

The novel and paradoxical finding of our current study is that acute stress combined with a parallel executive task did not impair decision making, as participants of this group performed as good as nonstressed single-task participants. Thus, the combination of the factors of stress and parallel task, which were associated with impaired decision making, if administered alone, did not cause an especially strong impairment, but rather rescued performance. It appears that the two impairing manipulations canceled each other out, at least at the behavioral level. How can this finding be explained? As mentioned earlier, studies also reported improved or unaltered PFC-dependent cognitive functioning evoked by acute stress (Kofman et al., 2006; Plessow et al., 2011). Plessow and colleagues (2011) investigated selective attention in a single-task setting and found similar task performance under stress compared with controls due to an increase in goal shielding. The question is whether these results are applicable to our findings and whether they may explain the unimpaired performance in stressed parallel-



task participants. We conclude that a satisfactory explanation may not be drawn from these results, as, in our study, unimpaired performance was found in the parallel-task group only and not in stressed single-task participants. In addition, the used paradigms are difficult to compare, as one is a selective attention task and the other assesses decision making under risk.

One possible explanation is that the two negative factors of stress and parallel task induced an altered response strategy, leading to an unequal usage of cognitive resources on both tasks. If resources were used to improve GDT performance, this strategy alteration should have resulted in a deterioration of 2-back task performance. This was not the case, and thus the reasonable explanation of a resource shift toward the GDT at the expense of the 2-back task prompted by acute stress can be rejected. Another explanation is supported by the finding that stress increases switch costs (Plessow, Kiesel, & Kirschbaum, 2012), which reflect the effort a person must make in order to actively monitor, pursue, and switch between two task goals (Spector & Biederman, 1976). Increased switch costs prolong task duration, which could have promoted GDT performance, giving the decision maker more time to scan alternatives. Such a strategy shift, however, did not take place as well, as the total number of 2-back trials did not differ between the stress and control groups of the parallel-task condition. Thus, the improvement of stressed compared with non-stressed parallel-task participants cannot be explained by an altered speed in task execution either.

An explanation relying on a stress-induced alteration in multi-tasking performance is a further possible approach. It has been postulated that switching between tasks may be processed in a serial, but also in a parallel, fashion (Raj et al., 2008; Verbruggen & Logan, 2008). A recent study has shown that acute stress evokes cognitive inflexibility, which leads to a shift from serial- to parallel-task monitoring as a simplified cognitive mode to process a task (Plessow, Schade, et al., 2012). As the combined GDT and 2-back task are displayed at the same time, both tasks may be performed almost simultaneously if not parallel. Thus, parallel goal monitoring can be beneficial for task performance, because of the omission of time required by goal shifting and the concomitant switch cost. A study with rodents has shown that a cognitive shift to a simplified response strategy does not necessarily involve impairment but may rescue performance (Schwabe, Schachinger, de Kloet, & Oitzl, 2010). This finding supports the hypothesis that a stress-evoked cognitive shift to a parallel and, at the same time, more simplified processing mode may benefit participants if two tasks must be performed simultaneously. To our knowledge, no research on decision making and parallel processing has been conducted to investigate such a hypothesis, which shows the necessity of additional investigations in this domain. Yet, using a dual-task paradigm, Plessow, Schade, and colleagues (2012) showed that acute stress induces a shift to a more parallel-task processing mode but did not impair performance. This shift was manifested by a stress-evoked reduction of task shielding. These results support our hypothesis of a shift from serial- to parallel-task processing after stress exposure.

How does stress induce a shift from serial- to parallel-task processing? The prefrontal-subcortical network of PFC and the nucleus accumbens is highly involved in decision making (Brand et al., 2006; Labudda et al., 2008). A recent review describes how exposure to controllable stress elevates dopamine concentrations,

leading to an activation of dopamine D2 receptors in prefrontal and subcortical areas (Cabib & Puglisi-Allegra, 2012). This activation may enable parallel processing by allowing multiple inputs to be processed simultaneously in the prefrontal network (Assadi et al., 2009).

If stress evokes a parallel task-processing mode, why do stressed participants with a parallel task show unimpaired decision making but the stressed single-task group does not? Plessow, Schade, and colleagues (2012) stated that stress evokes a less resource-demanding processing mode and that in a single-task setting, a strategy such as increased task-shielding (found in an earlier study, Plessow et al., 2011) may be most beneficial for performance. Yet in a setting in which parallel performance is required, stress may lead to a decrease in task shielding (Plessow, Schade, et al., 2012) and thereby may make parallel processing possible. In a parallel setting, this decrease would be considered the processing mode requiring fewer resources. Thus, we suggest that under stress, a parallel processing mode may only be evoked in a setting in which parallel performance is of actual relevance. Hence, stressed single-task participants may not have experienced a shift to parallel processing, as only one task was to be performed, and thus a need of decreased task shielding was not of necessity.

Further, our results suggest a moderation of decision-making performance under acute stress by the ability to divide attention (DA-ability) on simultaneously ongoing processes. It should be noted that the ability to divide attention is only one part of executive functions. Thus, its measurement does not cover the broad realm of executive functions. Yet we chose to measure DA-ability, as it may provide insights regarding the capability to perform multiple tasks at a time. We found a consistent performance in single-task participants for controls with a lower and higher DA-ability, and stressed participants with a higher DA-ability, but stress led to riskier decision making in single-task participants with a lower DA-ability. Interestingly, if two tasks had to be performed in parallel, stressed participants with a higher DA-ability showed a numerical improvement by choosing rather safe alternatives compared with controls of the same group, as shown in Figure 4. Stressed parallel-task participants with a lower DA-ability performed similar to controls.

Research has shown that participants with lower executive functions depend to a larger degree on learning from feedback for successful task performance as participants with higher executive functions (Brand et al., 2009). Higher executive functions may enable the decision maker to apply a strategy, which does not necessarily include feedback processing. As the vmPFC, including the orbitofrontal cortex, plays a vital role in learning from feedback (Bechara & Damasio, 2005), and as acute stress alters PFC functioning (Pruessner et al., 2008), dysfunctions in feedback processing may occur. This explanation is supported by research indicating that stress leads to an impairment of learning from negative feedback (Petzold, Plessow, Goschke, & Kirschbaum, 2010). Thus, acute stress may lead to poorer decision-making performance due to altered vmPFC functioning, but, as our results show, only in participants with a lower DA-ability in the single-task condition.

Starcke and colleagues (2008) found that stress impaired GDT performance, but not executive functions (executive functions measurement started right after stress induction until GDT performance approximately 30 min after stress induction). Additionally,

they investigated stress effects on decision making without receiving feedback, that is, no information about gains or losses of the single trials, using a modified GDT version. Here, a significant difference between the stress and the control group could not be found. They concluded that riskier decisions in the original GDT might occur due to disturbed feedback processing (Starcke et al., 2008). As decision makers benefit from higher executive functions, performance under stress may be as good as though they were not stressed. Another strategy may be used (e.g., a calculative approach) than learning from feedback. Hence, a stress effect in GDT performance may only be observed in decision makers with lower executive functions, as they are not capable of such a strategy shift and thus perform poorer under stress due to less effective feedback integration.

Based on our results, we speculate that participants with a higher DA-ability, compared with those with a lower DA-ability, had the greater benefit from the stress-evoked shift from serial to parallel processing. This benefit may result from the involvement of ACC-basal ganglia circuits in parallel information processing (Beste et al., 2012) and the positive relationship between this circuit and PFC activity (for a review, see Stocco, Lebiere, & Anderson, 2010). As higher executive functions seem beneficial in a stressful situation, it may be hypothesized that higher executive functions—in our case, a higher DA-ability—reflect an efficient interaction between basal ganglia and the PFC, thereby enabling a switch toward parallel processing under stress.

In summary, we replicated, although with smaller effect sizes, earlier findings of the impairing effect of acute stress (for a review, see Starcke & Brand, 2012) or a parallel executive task (Starcke et al., 2011), respectively, on decision making under risk. We found that acute stress in combination with a parallel executive task did not further impair decision making, but rather resulted in beneficial risk behavior indistinguishable from the control group. We speculate that this may be due to a stress-induced cognitive shift from serial to parallel goal monitoring. We also found that executive functions may play a moderating role in decision making with explicit and stable rules under stress. Additional research with tasks similar to the combined GDT and 2-back task is necessary to better understand the mechanisms underlying a cognitive shift from serial to parallel processing. Imaging studies could lead to insights in neuronal correlates of parallel processing and how these processes are evoked by stress. Further, it must be investigated how executive functions support decision making under stress, especially parallel goal monitoring, as our results indicated that a higher DA-ability does not only prevent an impairment of decision-making performance while performing a single task, but may lead to an improvement, if two tasks are performed in parallel.

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Received September 12, 2012

Revision received February 11, 2013

Accepted February 18, 2013 ■