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Anticipatory Stress Influences Decision Making Under Explicit Risk Conditions

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Recent research has suggested that stress may affect memory, executive functioning, and decision making on the basis of emotional feedback processing. The current study examined whether anticipatory stress affects decision making measured with the Game of Dice Task (GDT), a decision-making task with explicit and stable rules that taps both executive functioning and feedback learning. The authors induced stress in 20 participants by having them anticipate giving a public speech and also examined 20 comparison subjects. The authors assessed the level of stress with questionnaires and endocrine markers (salivary cortisol and alpha-amylase), both revealing that speech anticipation led to increased stress. Results of the GDT showed that participants under stress scored significantly lower than the comparison group and that GDT performance was negatively correlated with the increase of cortisol. Our results indicate that stress can lead to disadvantageous decision making even when explicit and stable information about outcome contingencies is provided.

Keywords: Game of Dice Task, cortisol, alpha-amylase, executive functions, emotional feedback processing

The question of how stress influences cognition and emotion has been addressed by several studies from various lines of research. A common method for inducing stress in the laboratory is instructing participants to deliver a public speech (Levenson, Sher, Grossmann, Newman, & Newlin, 1980; Steele & Josephs, 1988). This leads to the typical neuroendocrine stress responses (increase of the sympathetic nervous system and activation of the hypothalamus–pituitary–adrenal [HPA] axis). In addition, an increase in anxiety and negative mood occurs (al'Absi et al., 1997; Kudielka, Schommer, Hellhammer, & Kirschbaum, 2004). In humans, socioevaluative threat such as public speaking seems to be especially potent and leads to robust increases in cortisol levels, reflecting activation of the HPA axis (see review in Dickerson & Kemeny, 2004).

Various studies from different lines of research have shown that stress can lead to changes in prefrontal cortex functioning (e.g., Cerqueira, Almeida, & Sousa, 2008; Kern et al., 2008). Neuropsychological studies have examined the effects of stress on functions associated with the prefrontal cortex, such as memory and executive processes. However, results are quite heterogeneous depending on the level of stress, nature of the task, participant variables, and so forth. An inverted-u–shaped relationship between the level of stress and memory performance has been reported (see review in Lupien, Mahen, Tu, Fiocco, & Schramek, 2007). Executive functions have also been reported to be normal to enhanced (Kuhlmann & Wolf, 2006; Newcomer et al., 1999; Wolf, Convit, et al., 2001a) or decreased (al'Absi, Hugdahl, & Lovallo, 2002; Hsu, Garside, Massey, & McAllister-Williams, 2003; McCormick, Lewis, Somley, & Kahan, 2007) under stress or through the exogenous application of cortisol.

The effect of stress on decision making is of special interest because many decisions have to be made under stress in daily life. The results of neuropsychological investigations have suggested that stress might either benefit or disrupt decision making; in any case, however, a detrimental effect on decision making has been demonstrated (e.g., Garvey & Klein, 1993; Gray, 1999; Klein, 1996). A recent study by Preston, Buchanan, Stansfield, and Bechara (2007) investigated decision making under stress with the Iowa Gambling Task (IGT; Bechara, Tranel, & Damasio, 2000). The IGT is a card game that requires individuals to process feedback (gain or loss of fictitious money) to learn to avoid disadvantageous choices and to select advantageous alternatives. Rules for gains and losses are implicit, so every choice is full of ambiguity, and selections have to be made with the use of the emotional feedback from previous decisions. Individuals under stress learned the contingencies of the task more slowly than did individuals in the nonstress condition. Results have been interpreted in the context of the somatic marker hypothesis (Damasio, 1996) that proposes the development of internal somatic signals that usually guide decisions in an advantageous direction (Bechara & Damasio, 2005; Bechara, Damasio, Damasio, & Lee, 1999;

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Bechara et al., 2000). The task-unrelated emotions associated with stress were assumed to interfere with the development of somatic markers (see also Bechara & Damasio, 2005).

Further mechanisms underlying decision-making abilities may explain poor IGT performance in individuals under stress. In addition to investigating the influence of emotional feedback processing and somatic states, some studies have also questioned whether IGT performance relies on executive processes. However, results are inconsistent across studies. Hinson, Jameson, and Whitney (2002) and Jameson, Hinson, and Whitney (2004) reported poor IGT performance to be related to reduced executive processes (i.e., reduced attention capacities impair appropriate emotional feedback processing). In contrast, Turnbull, Evans, Bunce, Carzolio, and O'Conner (2005) found that a secondary executive task did not interfere with IGT performance and concluded that executive functions play a minor role in successfully performing the IGT. Because stress can lead to impediments in executive processes (see above), reduced executive functioning, in addition to impairments in feedback processing, have to be considered as a factor when participants perform poorly on the IGT after the induction of stress. A critical evaluation of the somatic marker hypothesis and a review of studies conducted with the IGT can be found in Dunn, Dalgleish, and Lawrence (2006).

The processing of an emotional feedback mediated by somatic signals is considered to be important in decisions under ambiguity as measured with the IGT. In addition, it has been demonstrated that decision making under ambiguity may be sensitive to stress-induced changes. However, nothing is known so far about the effects of stress on decisions under risk conditions. The Game of Dice Task (GDT; Brand et al., 2005) offers explicit and stable rules for gains and losses and is therefore able to explore this type of decisions. The GDT is a computerized game, and the goal of the player is to maximize a starting capital of fictitious money by choosing among different alternatives that consist of different combinations of dice. Every option is explicitly related to a specific amount of gain or loss and has obvious winning probabilities. After every selection, feedback about the money won or lost is provided (see also the *Method* section). Recent studies with the GDT have shown that task performance is related to executive functioning (e.g., Brand et al., 2005; Brand, Grabenhorst, Starcke, Vandekerckhove, & Markowitsch, 2007; Brand, Heinze, Labudda, & Markowitsch, 2008; Brand, Labudda, & Markowitsch, 2006), but also to emotional feedback processing (Brand, in press; Brand et al., 2006, 2007).

The aim of the present study was to investigate whether decision making under risk, measured with the GDT, is impaired by stress induced via the anticipation of a public speech. We measured the level of stress with questionnaires and assessed salivary cortisol (as a marker of HPA activity) and alpha-amylase levels (as a marker of sympathetic nervous system activity). We hypothesized that stress would impair GDT performance by disrupting feedback processing abilities, executive functioning, or both. To further address the question of whether stress predominantly disrupts emotional feedback processing or executive functions, we administered the GDT twice, once in the original version and once in a modified version in which no feedback was provided. Additionally, we tested executive functions independently of GDT performance.

Participants and Method

Participants

Forty-four students, aged 20 to 34 years were recruited from the University of Bielefeld, Bielefeld, Germany. Half of the students were randomly assigned to the experimental group (EG); the other half was assigned to the comparison group (CG). Exclusion criteria were a history of neurological or psychiatric disease or being a student of psychology. In addition, we excluded students who had previously participated in studies on decision making in the university's department of Physiological Psychology. Four students were eventually excluded from the study; 2 from the EG did not show increased stress levels after exposure to the stressor (they showed a decrease in anxiety and negative affect), and 2 from the CG showed an increase in anxiety and negative affect. Therefore, only 40 students were included in the statistical analysis. Recruiting and briefing of the participants complied with current German laws and ethical principles. All students gave written informed consent before the investigation and were paid €6 for their participation.

Method

Inducement of Stress

We used a cover story to induce stress in the EG. Students were told that they had to deliver a public speech on the topic "how I evaluate my cognitive abilities" in front of two psychologists after they had finished a number of neuropsychological tests. They were also informed that to compare actual performance with self-evaluation, the psychologists would ask questions regarding discrepancies. We chose the topic of the speech assuming that it would elicit stress in a student population given that cognitive abilities have a high relevance for male and female students because we aimed to exclude potential gender effects on stress reactions. A camera was placed on the desk to make students believe that the speech and the interview that followed the tests were being recorded. Students were given 3 min to prepare for the speech, and afterward the neuropsychological tests (including the decision-making tasks) were administered. Immediately after completing the experiment, however, students were told that they would not have to give an actual speech and that there would be no comparisons between self-evaluation and actual performance, and therefore no recording either. After the experiment, students were completely informed about our actual goal. In the time window in which stress was induced in the EG, the CG participants were told to think about their last holiday.

Measurement of Stress

To measure the change of stress levels in the EG and the CG, questionnaires and physiological indicators were used. The State Anxiety subscale of the State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1977) was used to assess anxiety and the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) was used to assess changes in positive and negative affect. Both questionnaires were administered before and after the induction of stress in the EG and at comparable times in the CG. We acquired endocrine indicators of stress by sampling salivary cortisol and salivary alpha-amylase (sAA) concentrations before and during the course of task performance. Both of the latter endocrine indicators have been found to increase during psychosocial stress, with cortisol levels rising as a result of HPA axis activity (see Dickerson & Kemeny, 2004) and sAA levels rising as a result of sympathetic nervous system activation (Nater et al., 2005; Rohleder, Wolf, Maldonaldo, & Kirschbaum, 2006; van Stegeren, Rohleder, Everaerd, & Wolf, 2006). Salivary cortisol and sAA levels were assessed by means of unstimulated saliva samples obtained using salivette collection devices (Sarstedt, Nuembrecht, Germany). To determine cortisol and sAA levels, the saliva samples were sent to Dresden, Germany, to the Kirschbaum laboratory. Free cortisol levels were measured using a commercially available immunoassay (IBL, Hamburg, Germany). Inter- and intraassay variations were below 10%. For sAA analysis, a quantitative enzyme kinetic method was used as described in detail elsewhere (van Stegeren et al., 2006).

Neuropsychological Tests

Intelligence. We assessed intelligence with the subtest of a German intelligence testing battery that measures logical reasoning, Subtest 4 of the *Leistungsprüfsystem* (Horn, 1983). The test consists of 40 rows of sequences of letters and numbers that follow a logical rule. Each row contains one element that does not logically fit the order of the row. Participants are given a time limit of 8 min to discover and cross out, in as many rows as possible, the illogical element.

Executive functions. We used the modified Wisconsin Card Sorting Test (Nelson, 1976) to measure concept formation and set shifting and the Trail Making Test Parts A and B (see Reitan & Wolfson, 1993) to measure psychomotor speed and mental flexibility. The Word–Color Interference Test (Bäumler, 1985), a German version of the Stroop test (Stroop, 1935), was used to assess interference susceptibility. The neuropsychological tests served a double function; first, they were used to compare performance between the EG and the CG; second, they served as an instrument in the cover story used in the EG. These particular executive tasks were chosen because they have also been administered in previous studies that examined decision making with the GDT (e.g., Brand et al., 2004, 2005, 2007, 2008). In the studies mentioned, an association between these executive tasks and GDT performance has been found, in particular in patient samples.

Decision-Making Task

To examine decisions under risk, we used the GDT (Brand et al., 2005). The GDT is a computerized game with the goal of maximizing a fictitious starting capital of €1,000. Participants have to choose between a single number and combinations of two, three, or four numbers that are permanently shown on the screen. A single die is thrown 18 times, and participants win if one of the chosen numbers is thrown; otherwise, they lose. Each choice is associated with explicit and stable gains and losses as well as winning probabilities: €1,000 gain–loss for the choice of a single number (winning probability 1:6), €500 gain–loss for two numbers (winning probability 2:6), €200 gain–loss for three numbers (winning probability 3:6), and €100 gain–loss for four numbers (winning probability 4:6). If a participant bets on the combination 5 and 6, for instance, and the 5 or the 6 is thrown, the participant wins €500; however, if one of the other numbers not chosen is thrown, the participant loses €500. The alternatives can be grouped into risky, disadvantageous decisions (one or two numbers with a winning probability of less than 34%) and safe, advantageous decisions (three or four numbers with a winning probability of 50% or higher). For the purpose of analysis, the net score of advantageous minus disadvantageous choices is computed. After participants have chosen an alternative, the die is thrown and the attained number, feedback regarding the gain or loss, the changed capital, and the remaining number of dice rolls are shown on the screen. The task simulates decisions under explicit and stable risk conditions in combination with feedback about the outcome of previous decisions. In this study, students performed the task twice: once as in the original version described above and once as a modified version (Brand, in press) in which no feedback about the outcome of previous decisions was provided. Neither the results of the dice rolls nor the financial gains and losses are shown on the screen in the modified task version. However, results are scored and participants are told that they will be able to see their final result after finishing the task.

Design and Procedure

The first salivary sample was taken after demographic information was acquired from the participants. Then the STAI (State Anxiety subscale) and PANAS were administered. After these baseline measurements of stress, stress was induced in the EG through the cover story of the speech (see description above). Students had 3 min to prepare their speeches and were told to make notes during this time. Following this instruction, the neuropsychological investigation began, with the modified Wisconsin Card Sorting Test being administered first. Afterward, the second salivary sample was taken. Neuropsychological testing was continued with the *Leistungsprüfsystem* Subtest 4, Stroop test, and Trail Making Test Parts A and B. Before the third salivary sample was taken, students were reminded of their speeches and were instructed to think about their notes. Thereafter, decision-making performance was tested with the GDT and the modified GDT in randomized order (half of the students first performed the original GDT and then the modified version, and the other half performed the two GDT versions in the reverse order). After completing the decision-making tasks, students again filled out the STAI (State Anxiety subscale) and the PANAS. Following this, students were told that they did not have to deliver a speech, and after a short relaxation period the last salivary sample was taken. During the period of stress induction in the EG, CG students were told to think about their last holiday. This was the only difference between the EG and the CG. The exact procedure assessed in the EG is presented in Figure 1. The schedule was chosen because cortisol responses have a latency of about 20–30 min after the beginning of a stressor (see Dickerson & Kemeny, 2004, and Kudielka et al., 2004). All investigations took place between 2 p.m. and 5 p.m. to ensure that there were no large variations in endocrine responses because of circadian changes (Kudielka et al., 2004).

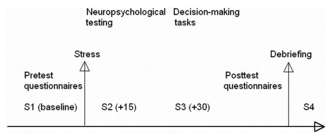

Figure 1. Design and procedure used in the experimental group. Numbers in parentheses indicate minutes after the beginning of the stressor. Arrows indicate the time point at which stress was induced and the time point at which participants were debriefed that they did not have to deliver a speech. S = salivary sample.

Results

Sociodemographic Variables

Groups did not differ in age (EG, $M = 24.75$ years, $SD = 3.99$; CG, $M = 23.75$ years, $SD = 3.18$), $t(38) = 0.88$, *ns*; gender (in both groups there were 9 male and 11 female students); and *t* scores of the intelligence test used (EG, $M = 62.93$, $SD = 6.24$; CG, $M = 61.73$, $SD = 7.23$), $t(38) = 0.56$, *ns*.

Level of Stress

Psychological indicators of stress. Comparison between groups showed that the EG had lower positive affect scores than the CG before stress was induced; however, negative affect and anxiety did not differ between groups. After the stress inducement, the EG had higher anxiety scores and higher negative and lower positive affect scores than the comparison group. Results are shown in Table 1. Within-group comparisons (*t* tests for dependent samples) showed a significant increase of anxiety, $t(19) = -5.25$, $p < .001$, $d = 1.75$, and negative affect, $t(19) = -3.30$, $p < .001$, $d = 1.14$, in the EG, whereas in the CG there was a decrease in both anxiety, $t(19) = 2.18$, $p < .05$, $d = .36$ and negative affect, $t(19) = 2.04$, $p < .05$, $d = .60$.

Physiological indicators of stress. We used analysis of variance with repeated measures to compare endocrine measures between groups with points in time as the within-subject factor and group as the between-subjects factor. Partial eta-square is given as effect size when appropriate. Results of the salivary cortisol samples revealed the expected elevation in the EG after stress induction and a decrease after the debriefing on a descriptive level. However, there was only a significant main effect for point in time, $F(1.61, 93) = 4.06$, $p < .05$, but not for group, $F(1, 31) = 1.73$, *ns*, and no interaction of Group × Point in Time, $F(3, 93) = 1.12$, *ns*. Results are shown in Figure 2. We also conducted the analysis with the baseline positive affect value as a covariate because groups differed in positive affect before the experimental manipulation. No significant effects for Positive Affect × Point in Time, $F(3, 93) = 1.10$, *ns*, and no interaction between Point in Time × Group controlled for positive affect, $F(3, 93) = 0.49$, *ns*, were observed. We also determined whether gender was a factor. No significant interactions for Point in Time × Gender, $F(3, 90) = 1.58$, *ns*; Point in Time × Group × Gender, $F(3, 90) = 0.08$, *ns*; or Group × Gender, $F(1, 30) = 0.56$, *ns*, were observed. The sAA measures revealed no significant main effects for point in time, $F(3, 72) = 1.61$, *ns*, or group, $F(1, 24) = 1.65$, *ns*, $\eta_p^2 = 0.06$, but a significant interaction of Group × Point in Time for higher elevation in the EG than in the CG, $F(3, 72) = 3.37$, $p < .05$, $\eta_p^2 = 0.12$, was observed. Results are shown in Figure 3. Including baseline positive affect as a covariate revealed no significant effect for Positive Affect × Point in Time, $F(3, 69) = 0.45$, *ns*. However, it led to an increased effect for group, $F(3, 69) = 3.67$, $p = .06$, $\eta_p^2 = 0.14$, but a decreased interaction effect of Group × Point in Time, $F(3, 69) = 2.56$, $p = .06$, $\eta_p^2 = 0.10$. No significant interactions of Gender × Point in Time, $F(3, 66) = 0.24$, *ns*; Gender × Group × Point in Time, $F(3, 66) = 0.08$, *ns*; or Gender × Group, $F(1, 22) = 1.21$, *ns*, were observed.

Decision-Making Task

On the original GDT (with feedback), the EG had a significantly lower net score than the CG (EG, $M = 7.60$, $SD = 9.08$; CG, $M = 14.20$, $SD = 4.14$), $t(26.61) = -2.96$, $p < .01$. Within the EG, there was a large interindividual variability not observed in the CG. The result of the Levene test ($p < .01$) also revealed that variances were not homogeneous among groups. Results of the GDT net score are shown in Figure 4.

To determine possible effects of gender, we performed a univariate ANOVA with GDT net score as the dependent variable and group and gender as factors. There was a main effect only for group, $F(1, 36) = 9.55$, $p < .01$, but not for gender, $F(1, 36) = 1.65$, *ns*, and no interaction of Group × Gender, $F(1, 36) = 1.26$, *ns*. Comparisons of the single alternatives revealed that the EG selected the risky two-number combination (winning probability 33.33%) significantly more often than did the CG, $t(31.21) = 2.74$, $p < .01$, after correction for multiple comparisons. Results of the

Table 1
Results of the Questionnaires Assessing Psychological Indicators of Stress in the Experimental and Comparison Groups

Questionnaire	Experimental group (*M* [*SD*])	Comparison group (*M* [*SD*])	*t*(38)	*p*
STAI-State-1	38.75 (5.75)	37.05 (5.99)	0.92	.37
STAI-State-2	47.15 (8.77)	35.00 (5.47)	5.26	< .001
PANAS-PA-1	25.50 (5.55)	29.35 (3.86)	−2.52	< .05
PANAS-PA-2	23.95 (5.66)	29.40 (4.20)	−3.46	< .001
PANAS-NA-1	12.80 (2.53)	12.45 (3.36)	0.37	.71
PANAS-NA-2	15.15 (4.08)	11.25 (2.15)	3.78	< .001

Note. *t* tests (two-tailed) for independent samples were used. STAI = State–Trait Anxiety Inventory; PANAS = Positive and Negative Affect Schedule; PA = Positive Affect; NA = Negative Affect.

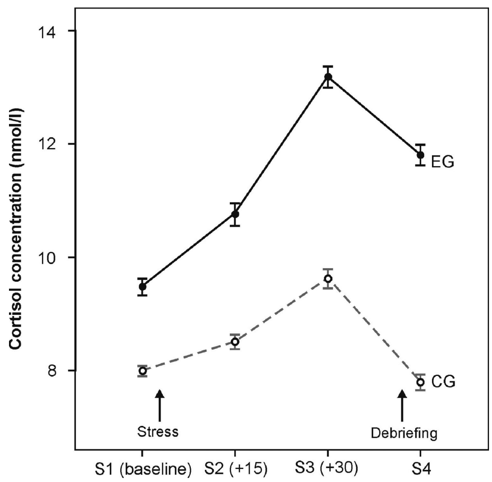

Figure 2. Results of the cortisol measures in the experimental group (EG) and comparison group (CG) at the four points of measurement. Numbers in parentheses indicate minutes after the stress inducement. Error bars represent standard errors. S = salivary sample.

single alternatives chosen by the EG and CG are presented in Figure 5.

In the modified GDT (without feedback), net scores did not differ significantly between groups (EG, $M = 7.20$, $SD = 9.93$; CG, $M = 12.10$, $SD = 7.18$), $t(38) = -1.79$, $p = .08$, although—on a descriptive level—the EG had a lower total net score than the CG. Note that both groups showed slightly lower performance on the modified GDT than on the original GDT. In a univariate ANOVA examining the effects of group membership and gender on the modified GDT, no significant effects for group, $F(1, 36) = 2.92$, *ns*; gender, $F(1, 36) = 0.14$, *ns*; or interactions between both factors, $F(1, 36) = 0.08$, *ns*, were observed.

Relationships Between Decision Making and Indicators of Stress

When analyzing the relationship between decision making (GDT original version) and stress, we first examined whether positive affect was related to decision-making performance because the EG scored lower on the positive affect scale before stress was induced than did the CG. We conducted a univariate ANOVA with GDT net score as the dependent variable, group as a factor and the PANAS pretest score as a covariate. There was no significant effect for the PANAS pretest score, $F(1, 37) = 0.11$, *ns*, and the effect for group remained significant, $F(1, 37) = 8.01$, $p < .01$. Correlation analysis also revealed that the PANAS pretest score was unrelated to GDT performance ($r = .12$, *ns*); therefore, we concluded that differences in GDT performance were not because of differences in positive affect that existed before the experimental manipulation. The changing stress levels between pre- and posttest measures were quantified with cortisol- and sAA-level delta increases used in previous studies (e.g., Wolf, Schommer, Hellhammer, McEwen, & Kirschbaum, 2001): The baseline value was subtracted from the value at the third point of measurement (30 min minus baseline). We performed correlations between delta increases and GDT performance for all participants. The GDT net score was negatively correlated with the cortisol delta index ($r = -0.34$, $p < .05$), which means that students who had a higher increase in cortisol responses scored lower on the GDT. Additionally, there was a significant correlation between the cortisol delta increase and the choice of the riskiest one-number alternative (winning probability = 16.66%; $r = .46$, $p < .01$), which means that students who had a high increase in cortisol chose the most disadvantageous option more frequently. Correlations between sAA delta increase and GDT performance failed to reach significance for both net score ($r = -0.25$, *ns*) and one-number alternative ($r = .31$, *ns*).

Executive Functions

Groups did not differ in any of the executive tasks assessed. Results are shown in Table 2. We did not find any significant correlations between executive functions and decision making, neither including all students nor within each of the two groups.

Discussion

The main result of this study demonstrates that the EG performed lower on the GDT than did the CG, indicating that stress can affect decision making even in a situation with explicit and stable rules for reward and punishment.

As a necessary precondition for interpreting results of the decision-making performance, the anticipation of giving a public speech was effective as a stressor. It significantly increased anxiety and negative affect and sAA secretion in the EG but not the CG. The topic of the speech, "how I evaluate my cognitive abilities," that we pretended to compare with actual cognitive performance is seen as stress eliciting because it implies a social evaluative threat. Results are in line with previous studies that have demonstrated that public-speaking tasks enhance anxiety and negative affect

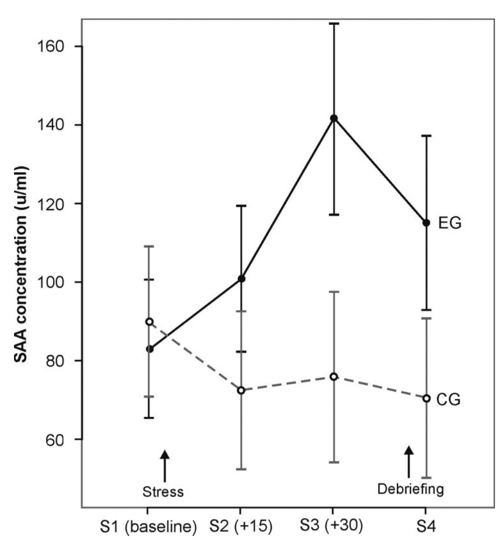

Figure 3. Results of the alpha-amylase measures (sAA) in the experimental group (EG) and comparison group (CG) at the four points of measurement. Numbers in parentheses indicate minutes after the stress inducement. Error bars represent standard errors. S = salivary sample; u = units.

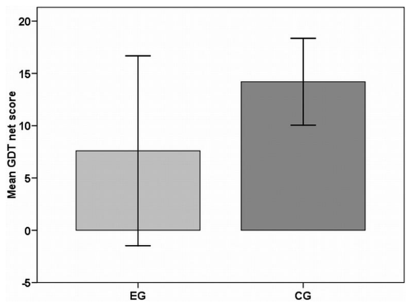

Figure 4. Mean net scores (number of advantageous choices minus number of disadvantageous choices) of the experimental group (EG) and comparison group (CG) from the original Game of Dice Task (GDT). Error bars represent standard deviations.

(e.g., al'Absi et al., 1997; Steele & Josephs, 1988). Additionally, recent studies have shown that sAA secretion, which is under adrenergic control and therefore an indirect marker of sympathetic nervous system activity, increases during psychosocial stress tasks (Nater et al., 2005; Rohleder et al., 2006). Cortisol reactions, under control of the HPA axis, are established endocrine markers of psychosocial stressors (see review in Dickerson & Kemeny, 2004). Our results also show the expected reaction pattern in the EG (elevation after the stress induction and decrease after the debriefing); however, group differences between the EG and the CG failed to reach significance. A recent study by Labudda, Wolf, Markowitsch, and Brand (2007) revealed that the decision-making task used does not elicit stress itself in healthy participants; thus, any confounding effects between stress related to GDT performance and stress related to the experimental manipulation can be evaluated as being rather minimal.

As previously stated, our main finding is that subjects in the stress condition performed significantly poorer in the GDT than did comparison subjects with regard to choosing the disadvantageous options more frequently. To our best knowledge, this is the first study investigating the effect of stress on decision making under risk conditions in a task with explicit and stable rules. Correlation analysis showed that the increase of cortisol was negatively correlated with decision making; thus, the more cortisol increased, the worse students performed on the task. Our main prediction—that stress can disrupt decision-making abilities under risk conditions—was confirmed by our data, as indicated by group differences and correlation data. However, there was a large interindividual variability on GDT performance in the EG compared with the CG. This finding indicates that not all students made risky decisions when exposed to the stressor, but that stress acts by increasing variability in GDT performance. The question of why some individuals are susceptible to stress-induced disadvantageous decision making whereas others are resistant to those effects has to be addressed in future studies.

Our results are in line with the findings of a recent study conducted by Preston et al. (2007), who found a reduced learning curve in participants under stress in decision making under ambiguity measured with the IGT. They concluded that stress can impair emotional feedback learning and the development of somatic markers necessary for solving the IGT (see also Bechara & Damasio, 2005). They also found gender effects—namely, a higher stress response of female compared with male participants, but at the same time a better performance of stressed female participants compared with male participants. In the current study, we did not find interactions between gender and response to the stressor or decision-making performance. This may be because the topic of the cover story focused on cognitive abilities, a topic relevant for all students, male or female. In contrast, previous studies used cover stories consisting of concerns about physical appearance, and female participants may be more sensitive to that.

Although the IGT is strongly associated with emotional feedback processing and the development of somatic markers, the GDT is not only associated with feedback processing (Brand, in press; Brand et al., 2006, 2007), but also particularly with executive functioning (Brand et al., 2004, 2005, 2006, 2007, 2008). Impairments in one of these two processes are supposed to lead to disadvantageous decision making. We wanted to investigate whether stress affected feedback processing, executive functioning, or both when the GDT was performed under stress. Therefore, we tested executive functioning independently of GDT performance and administered not only the original GDT, but also a modified version in which no feedback about the outcomes of previous decisions was provided. Contrary to some studies (Hsu et al., 2003; McCormick et al., 2007), but in line with others (Kuhlmann & Wolf, 2006; Newcomer et al., 1999; Wolf, Convit, et al., 2001), we found that participants under stress performed at a normal level on all of the executive tasks used in the study. Therefore, we have concluded that it was not the executive component of the GDT that was disrupted by the stressor. In addition, executive functioning was not significantly related to GDT performance in either of the groups. This finding somehow contrasts findings of previous studies conducted with the GDT. Associations between executive functions and GDT performance have frequently been reported in patient studies (Brand et al., 2004, 2005, 2006, 2007) and in a study with healthy participants (Brand et al., 2008). Note that in both groups of the current study (highly

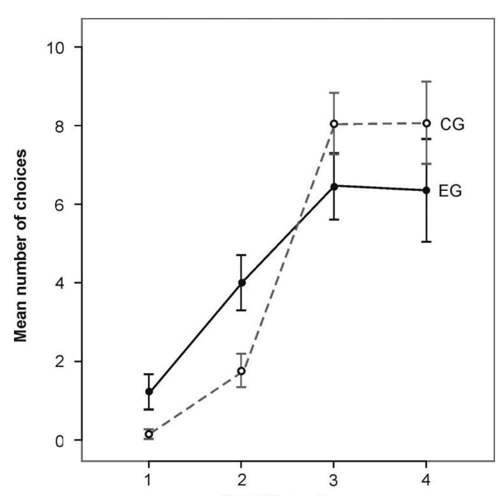

Figure 5. Single alternatives chosen by the experimental group (EG) and comparison group (CG) in the original Game of Dice Task (GDT). One and two numbers are risky choices; three and four numbers are safe choices. Error bars represent standard errors.

Table 2
Results of the Neuropsychological Test Battery in the Experimental and Comparison Groups

Tests and subtests	Experimental group *M* (*SD*)	Comparison group *M* (*SD*)	*t*	*df*	*p*
Word Color Interference Test					
Reading the word[a]	53.00 (7.27)	51.10 (6.28)	0.87	37	.39
Naming the color[a]	58.47 (9.22)	58.40 (7.92)	0.03	37	.98
Interference trial[a]	55.37 (6.73)	57.55 (6.95)	−0.99	37	.38
Trail-Making Test A[b]	55.79 (28.10)	60.25 (18.95)	−0.58	31.37	.57
Trail-Making Test B[b]	54.17 (30.21)	59.00 (25.93)	−0.52	35	.60
Modified Wisconsin Card Sorting Test					
Correct[c]	43.35 (4.27)	44.35 (2.78)	0.88	38	.39
Nonperseverative errors[c]	3.90 (3.39)	3.10 (2.36)	0.87	38	.39
Perseverations[c]	0.75 (1.16)	0.55 (0.60)	0.68	28.56	.50

Note. *t* tests for independent samples (two-tailed) did not indicate any differences between groups.
[a] *t* scores. [b] Percentiles. [c] Raw scores.

educated participants, students only), executive functions were relatively high and ceiling effects could account for the nonsignificant correlations between executive measures and GDT performance. There is also the possibility that executive functions other than those tested are involved in decision making and that they were affected by the stressor, considering the fact that executive functions are quite heterogeneous. However, the particular functions tested were similar to those of previous studies that have demonstrated a relationship between GDT performance and executive functioning (e.g., Brand et al., 2005, 2007, 2008). In the modified GDT (without feedback), both groups performed slightly worse than in the original GDT, similar to results of a previous study (Brand, in press). Group differences diminished although—on a descriptive level—the CG still performed better than the EG. In the modified GDT, the development of somatic markers is supposed to play a minor role because feedback cannot be used for future decisions. Interpreted in the context of the somatic marker hypothesis, poor performance of the EG in the original GDT may be because of stress-associated emotions that interfered with feedback-processing abilities and the development of somatic markers. In line with the previously mentioned study by Preston et al. (2007), the nonstressed participants were able to use the feedback for future decisions, whereas the stressed participants had difficulties in doing so. Future research including physiological measures should investigate the role of somatic markers during GDT performance when participants are stressed. A previous study has shown that advantageous and disadvantageous decisions are differentially related to skin conductance responses in healthy participants (Brand et al., 2007), and the question of whether these physiological correlates of decision making decrease when task-unrelated emotions interfere has to be addressed.

Concerning neural mechanisms underlying decision-making processes, our results provide support that functioning of the prefrontal cortex was affected by the stressor, in line with previous studies (e.g., Cerqueira et al., 2008; Kern et al., 2008). More specifically, results indicate that the stressor influenced orbitofrontal cortex and limbic system functioning. The orbitofrontal cortex interacting with the amygdala is critical for emotional feedback learning and the development of somatic markers, as has been demonstrated by functional imaging and patient studies (see review in Dunn et al., 2006). The stress-associated emotions like fear and anxiety may have detrimental effects on decision making through the release of hormones in response to stress that have receptors in the orbitofrontal cortex and amygdala (Roozendaal, McReynolds, & McGaugh, 2004; Sapolsky, 1992). In contrast, our results do not indicate that the stressor affected functioning of the dorsolateral prefrontal cortex, which is seen as critical for executive processes (Brand et al., 2006; Ernst & Paulus, 2005; Krain, Wilson, Arbuckle, Castellanos, & Milham, 2002). Executive processes were at normal levels in our EG. Elevated dopamine release in the striatum during stress has been reported in previous studies (Adler et al., 2000; Pappata et al., 2002; Pruessner, Champagne, Meanes, & Dagher, 2004); however, it might be the case that this process did not occur in our EG or that higher dopamine levels did not affect dorsolateral prefrontal cortex functioning in our stressed participants. A caveat has to be stated as we cannot rule out that hormones released in the dorsolateral prefrontal cortex affected executive functions other than those tested.

In summary, our results indicate that stress is disruptive to decision making in a task with explicit and stable rules that relies on executive processes and feedback learning. One explanation could be that the task-unrelated emotional stress impairs feedback learning and the development of somatic markers to such an extent that the effect cannot be compensated for through intact executive processes. Results also demonstrate the risk of making disadvantageous decisions when stressed, even in decision situations that provide explicit information about contingencies.

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