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RESEARCH REPORT

Decision-making under risk conditions is susceptible to interference by a secondary executive task

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Abstract Recent research suggests two ways of making decisions: an intuitive and an analytical one. The current study examines whether a secondary executive task interferes with advantageous decision-making in the Game of Dice Task (GDT), a decision-making task with explicit and stable rules that taps executive functioning. One group of participants performed the original GDT solely, two groups performed either the GDT and a 1-back or a 2-back working memory task as a secondary task simultaneously. Results show that the group which performed the GDT and the secondary task with high executive load (2-back) decided less advantageously than the group which did not perform a secondary executive task. These findings give further evidence for the view that decision-making under risky conditions taps into the rational-analytical system which acts in a serial and not parallel way as performance on the GDT is disturbed by a parallel task that also requires executive resources.

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Introduction

The question how cognitive and emotional processes contribute to decision-making has a long research tradition. The dual-process theory (Kahneman 2003; Epstein et al. 1996; Evans 2003) postulates two ways of making decisions. The first one is the so-called intuitive-experiential system (which acts fast, parallel, associative, emotional etc.), also referred to as either natural or heuristic, or simply system 1 (Kahneman 2003; Kahneman and Frederick 2007; Epstein et al. 1996; Evans 2003). The second is a rational-analytical system (Epstein et al. 1996) also referred to as extensional (Tversky and Kahneman 1983), or system 2 (cf. Evans 2003; Stanovich and West 2000) which is linked to slow and serial but controlled, flexible, neutral, rule-governed, and effortful information processing (e.g., Kahneman 2003). There is a current debate which system is better suited to make the best decisions: While some authors consider fast and frugal heuristics (system 1) to be most powerful (Marewski et al. 2010a, b), others emphasize the important impact of logical reasoning (system 2) under some circumstances and in some situations or postulate a coexistence of heuristics and logical reasoning (Evans and Over 2010). Daw et al. (2005) focus on the interaction between systems in general and when they disagree. They suggest that organisms calculate the relative uncertainty of the predictions made by each system using a Bayesian principle. The relevance and actuality of this research topic is also reflected, for example, by a current special issue on Complex Cognition (edited by Knauff and Wolf) published in Cognitive Processing (2010, Volume 11, Issue 2) in which some articles explicitly address the dual-process approaches.

A similar distinction has been made in neuropsychological decision-making research, in which decisions under ambiguity and decisions under risk are differentiated commonly (Brand et al. 2006). Decisions under ambiguity are those which have to be made via intuitive processes based on previous experiences, because the decision situations do not offer explicit rules for possible outcomes or probabilities (Damasio 1996). A task frequently used to measure decisions under ambiguity is the Iowa Gambling Task (IGT; Bechara et al. 2000; Bechara et al. 1994). Studies investigating patients with lesions or dysfunctions of certain brain areas and functional imaging studies in healthy participants indicate that the ventromedial/orbitofrontal prefrontal cortex and the limbic system are involved in solving the task (Dunn et al. 2006; Buelow and Suhr 2009). Due to the predominant role of emotions for successful task performance under ambiguous conditions, it was supposed that executive functions play a minor role. To test hypothesis that the task relies predominantly on system 1, it was investigated whether a secondary executive task that requires cognitive resources from system 2 interferes with IGT performance (Turnbull et al. 2005). Three groups of participants performed either the IGT without a secondary task, the IGT, and a simultaneous secondary executive task, or the IGT and a simultaneous secondary non-executive task. All groups performed similarly on the IGT meaning that they had comparable learning curves over the task. Consequently, the authors concluded that the secondary executive task did not interfere with the IGT because the two tasks require different cognitive resources. They also concluded that the IGT can be performed on the basis of intuition and experiences and therefore taps into the intuitive-experiential system (system 1; Kahneman 2003; Kahneman and Frederick 2007; Epstein et al. 1996; Evans 2003; see Turnbull et al. 2005 for a more detailed discussion).

On the other hand, decisions under risk conditions are characterized by situations which offer explicit rules for reinforcement and punishment and further information necessary for calculating potential outcomes. Such decisions can be assessed, for example, with the Game of Dice Task (GDT; Brand et al. 2005a). In this task, the different options differ with respect to their risk of winning or losing. Although the exact outcome is also unknown to the participant, the options can be categorized into “more risky” and “less risky” on the basis of the information about the contingencies which is explicitly provided from the beginning of the task. In addition, feedback after each decision is also given, and the task can therefore be solved via both, strategy application and emotional feedback processing (for task description see the methods section). Recent studies with the GDT have shown that some patient groups with executive dysfunctions due to lesions or dysfunctions of the dorsolateral prefrontal cortex show disadvantageous decision-making i.e., they make more risky choices (Brand et al. 2004a, b, 2005a, b). Patients with lesions of the amygdala only make disadvantageous decisions if they also have executive dysfunctions (Brand et al. 2007). A recent imaging study with fMRI found activations of the dorsolateral prefrontal cortex in healthy participants (Labudda et al. 2008) when performing decision trials that were comparable to that used in the GDT. Recent studies with healthy participants also indicate that task performance is related to executive functioning as well as emotional feedback processing. Correlations have been found with executive functions such as concept formation and set shifting, interference susceptibility (Brand et al. 2009; Brand et al. 2008), and working memory (Brand, unpublished results). A recent study demonstrated that feedback processing is also an important component of the GDT (Brand 2008). Performance decreased if no feedback was provided.

Thus, studies indicate that the GDT relies not only on the intuitive system (system 1) but also on the rational-analytical system (system 2; Brand et al. 2006). Until now, there are no studies that investigated the effect of a secondary executive task on decision-making under risk conditions comparable to the study by Turnbull et al. (2005). We hypothesized that a secondary executive task disrupts decision-making under risk conditions because both tasks require cognitive resources from system 2.

Participants and methods

Participants

One hundred and twenty participants aged 19–44 years (mean = 24.01, SD = 4.99; 31 males) were recruited from the Universities of Duisburg-Essen and Koblenz-Landau. Exclusion criteria were a history of neurological or psychiatric disease as determined by a screening interview. Participants were randomly assigned to one of the following conditions: original GDT without secondary task ($n = 40$), GDT with secondary 1-back task ($n = 40$), GDT with secondary 2-back task ($n = 40$). The study was approved by a local ethics committee of the University of Duisburg-Essen (Department of Computer Science and Applied Cognitive Science).

Methods

To examine decisions under risk, the GDT (Brand et al. 2005a) was used. 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 virtual single die is thrown 18 times, and participants win if the chosen number or 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 "five" and "six" for instance, and the five or the six is thrown, the subject wins 500 €, but if one of the other numbers not chosen is thrown, 500 € are lost (see Fig. 1). The alternatives can be grouped into risky, disadvantageous decisions (one or two numbers with a winning probability less than 34%) and safe, advantageous decisions (three or four numbers with a winning probability of 50% and higher). After participants have chosen an alternative, the alternative is marked minimally (the frame of the chosen combination slightly turns from white to gray) and the die is thrown. Then, the shaker is lifted up, and the attained number becomes visible. A visual and auditory feedback of the gain or loss is given. Gains are presented in green accompanied by the sound of a cash box; losses are presented in red accompanied by an unpleasant sound. The changed capital and the remaining number of trials are shown on the screen. No time limit for decisions in the GDT is given.

As a secondary executive task, the n-back task had to be performed simultaneously to the GDT. The two tasks were shown on the same computer screen which means that the

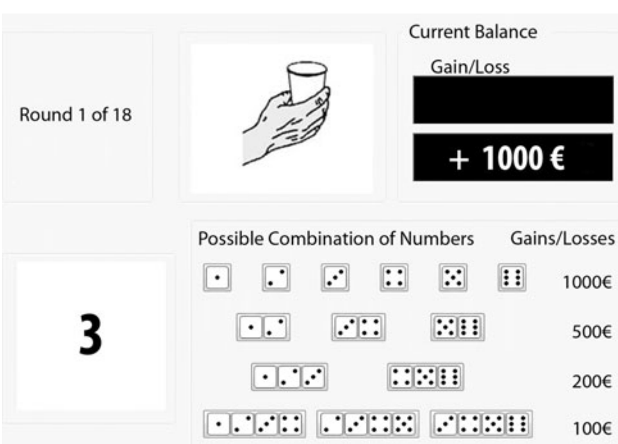

Fig. 1 The GDT plus n-back task. The hand with the shaker symbolizes the shaking of the die. It is moving during the time the participant can make a decision and put down after the decision is made. Then, the shaker is lifted up, and the die becomes visible

n-back was included into the GDT on the left side of the GDT screen. In the n-back task, participants have to monitor the identity of numbers from "0" to "9". Numbers were presented in a random sequence, and participants had to indicate whether the currently presented number was the same as the one presented n trials previously (either 1-back or 2-back). The numbers were displayed for 500 ms with an inter-stimulus interval of 2,750 ms. Thus, participants had a time limit of 500 ms for making their response. A visual feedback if the response was correct was given with a green check mark indicating success and a red cross indicating failure. Target stimuli were presented randomly with a probability of 33% (Schoofs et al. 2008). The GDT plus n-back task can be seen in Fig. 1.

Participants had to use their left hand for solving the n-back task (pushing a button indicating target stimulus or not) and their right hand for selecting the options on the GDT. Handedness was not assessed. Both tasks were explained and practiced separately before the task started. For the purpose of analysis, a GDT netscore is computed. The number of risky, disadvantageous decisions is subtracted from the number of safe, advantageous decisions. A net score above zero implies that the participant selected more advantageous than disadvantageous options. The performance in the n-back task is computed as the percentage of correct responses.

Statistical analysis

All analyses have been carried out with SPSS 17.0. Pearsons x^2 test was used to compare groups concerning gender. One-way ANOVAs were used to compare groups for age, GDT netscore, number of riskiest choices, and shifting behavior. Scheffè's post hoc procedure was used to analyze the group differences in GDT performance in detail. Cohens d was used as effect size when appropriate. T-test for independent samples was used to compare the performance of the 1-back and 2-back tasks. The relationship between performance in the GDT and n-back task was computed using Pearson's correlation. Two-tailed tests were performed for all analyses, and p was set to .05.

Results

Groups did not differ concerning age and gender (see Table 1).

As a main effect, groups differed in the GDT netscore. Single comparisons between the three groups indicated that the GDT netscore was significantly higher in the group which performed the GDT solely than in the group which performed the GDT plus the 2-back task ($P < .05$, $d = .67$), whereas the difference between the original GDT

Table 1 Demographic variables in the three conditions

	Original GDT M (SD)	GDT plus 1-back M (SD)	GDT plus 2-back M (SD)	F	X^2	df	P
Age	24.00 (5.20)	23.97 (4.86)	24.05 (5.03)	.00		2, 117	.99
Gender	30 f/10 m	29 f/11 m	30 f/10 m		.09	2	.96

Table 2 Results of the GDT in the three conditions

	Original GDT M (SD)	GDT plus 1-back M (SD)	GDT plus 2-back M (SD)	F	df	P
GDT netscore	12.35 (6.13)	7.95 (9.05)	6.80 (9.96)	4.71	2, 117	<.01
Riskiest choice	0.73 (1.22)	2.25 (3.88)	3.03 (4.34)	4.66	2, 117	<.01

group and the group which performed the GDT plus the 1-back task slightly failed to reach significance ($P = .07$, $d = .57$). As a further main effect, the three groups also differed in selecting the riskiest choice (the 1-number alternative). Post hoc comparisons revealed that the frequency of selecting the riskiest choice was significantly higher in the GDT plus 2-back group than GDT solely group ($P < .05$, $d = .72$). Again, the difference between the original GDT and the GDT plus 1-back task failed to reach significance ($P = .14$, $d = .53$). Results can be seen in Table 2. The group difference in the GDT netscore (safe minus risky choices) remains significant if the riskiest choice was excluded ($F(2, 117) = 3.57$, $P < .05$). Post hoc comparison again reveals a lower netscore of the GDT 2-back group compared to the GDT original group ($P < .05$, $d = .56$).

Results of the single alternatives chosen by the three groups can be seen in Fig. 2.

We also analyzed how often participants shifted between the alternatives and if they used the given feedback. Feedback processing was calculated as the percentage of shifting from a risky to a safe alternative and vice versa after a feedback of gain or loss. Groups did not differ in their overall number of shifting between alternatives ($F(2, 117) = .09$, $P = .91$). Concerning usage of the feedback, groups did not differ in their shifting behavior after risky choices no matter if a gain or loss was received (all P's > .05). A significant group difference was observed after safe choices if a positive feedback was given ($F(2, 113) = 3.33$, $P < .05$). Post hoc comparisons revealed that participants in the 2-back group more often shifted from a safe to a risky choice compared to the original GDT group ($P < .05$, $d = .57$).

The 1-back task was performed more accurately than the 2-back task (mean 1-back = 84.60%, SD = 11.29%; mean 2-back = 72.38%, SD = 9.71%; $t(78) = 5.19$, $P < .001$).

A positive correlation was found between the GDT netscore and the percentage of correct responses in the n-back tasks (1-back and 2-back as a measure of overall working memory performance; $r = .23$, $P < .05$). Thus, better performance in the working memory task was associated with better performance (less risky choices) in the GDT.

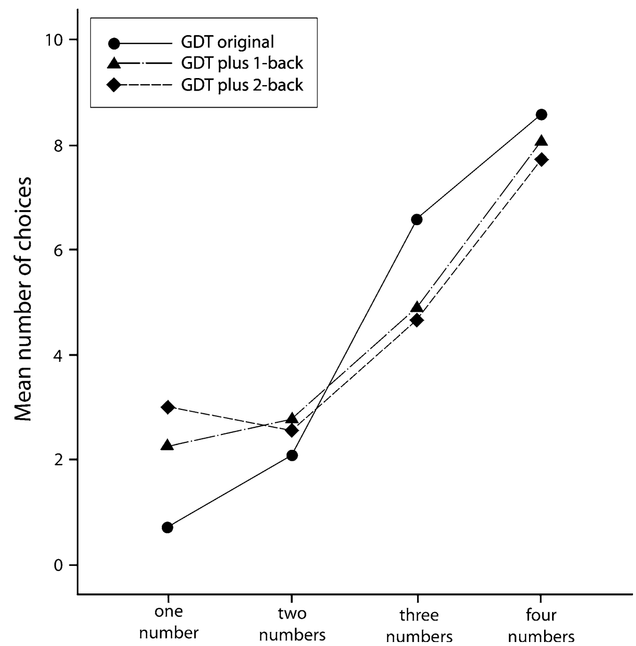

Fig. 2 Results of the single alternatives chosen by the three groups

Discussion

The main finding of the current study is that participants' performance in decision-making under explicit risky conditions decreased when a secondary executive task with high executive load had to be performed simultaneously.

The main result suggests that cognitive resources required for GDT performance and executive functioning overlap and therefore that decision-making under risky conditions tap into the rational-analytical system (system 2; Tversky and Kahneman 1983; Evans 2003; Epstein et al. 1996; Stanovich and West 2000; Kahneman 2003). This finding is in contrast to that revealed by Turnbull et al. (2005)

who investigated the question of whether or not IGT performance can be reduced by performing a secondary task simultaneously—which was not the case in their study. It has been concluded by Turnbull et al. that cognitive resources required for IGT performance and executive functioning do not principally overlap. Clinical studies also indicate that patients with lesions of the dorsolateral prefrontal cortex show working memory deficits but no deficits in the IGT (Bechara et al. 1998). Accordingly, the results of the current study also further emphasize the distinction between decisions under risk conditions and decisions under ambiguity. The reason for the diverging results for IGT and GDT as found by Turnbull et al. (2005) and in the current study may be based upon the different cognitive and emotional processes that are involved in IGT vs. GDT performance. While the IGT can be solved via emotional feedback processing resulting in an intuition (in the sense of implicit knowledge (see Bechara et al. 1997) which card decks are good or bad, the GDT can also be solved via strategy application such as the categorization of options and the recognition of probabilities (see Brand et al. 2008). This argumentation is principally in accordance with theories of general decision-making, i.e., the dual-process theory (Kahneman 2003) as well as with theories or models on decision-making from a neuropsychological perspective (Brand et al. 2006). The model of decision-making under risk conditions proposed by Brand et al. incorporates both, strategies and emotional feedback processing as determinants of advantageous decisions. If one of the paths is impaired, decisions should be less advantageous than if both paths are intact but still better than if both paths are impaired.

In the current study, the performance in the two tasks (GDT and n-back) is correlated. This is in line with studies showing correlations between performance in the GDT and executive functions such as concept formation and set shifting and interference susceptibility in patient groups (Brand et al. 2004a, b; 2005a, b) as well as healthy participants (Brand et al. 2008, 2009). Furthermore—although still unpublished—evidence for the correlation between working memory and performance in the GDT can be found in a very recent study (Brand, unpublished results). Healthy participants performed the GDT and a 3-back task separately. Poor performance in the 3-back task was associated with the choice of the most risky alternative indicating poor working memory covaries with risky and therefore dysfunctional decision-making. In the current study, the weak but significant correlation between GDT and n-back performance indicates that tasks require similar but also unique cognitive resources. This is in line with the model by Brand et al. (2006) considering working memory one of many necessary predecessors for making an advantageous decision. More specifically, situation features (e.g., task instructions), recall of knowledge and experiences with probabilities (e.g., knowing that a probability of 4:6 is higher than of 1:6), and consequences (e.g., knowing that a gain is better than a loss) and previous decision situations (e.g., knowing which choice has currently been made or which choices were followed by gains and losses) have to be represented in working memory.

When looking at the specific results of the n-back tasks, one can see that the 1-back task has been performed more accurately than the 2-back task suggesting a higher executive load of the 2-back task (see also Jaeggi et al. 2009). Performing the secondary task with higher executive load disrupted advantageous decision-making, whereas performing the secondary task with lower executive load did not lead to a significant deterioration in decision-making. However, on a descriptive level, the participants who did not perform a secondary task decided more advantageously than participants performing any secondary task and the effect sizes point in the same direction.

To further disentangle which component of the GDT interferes with the working memory task (implementing, maintaining, or monitoring a strategy), the shifting behavior was compared between groups. The number of shifts between alternatives did not differ between groups; thus, perseveration or alternation tendencies due to limited attention resources in the n-back groups can be excluded. Typical abnormal feedback processing such as staying at a risky alternative despite negative feedback has not been found either in the n-back groups. However, the 2-back compared to the original GDT group more often shifted from a safe to a risky alternative despite having received a gain. This might reflect a partial difficulty of strategy monitoring under 2-back conditions.

A limitation of the current study is that it focussed on the question if a secondary executive task interferes with decision-making under risk conditions. This means that it is still unclear whether the reductions in decision-making under risk can be provoked by a secondary executive task specifically or whether also non-executive secondary tasks may also interfere with GDT performance. Future studies should investigate the specificity of interference between GDT and executive or non-executive secondary tasks, respectively. As the GDT is not only solvable via executive processes but also via emotional feedback processing of previous gains and losses, it might be that also secondary tasks which interfere with emotional processing may disrupt GDT performance. The same should be applied to the IGT. In a previous study, we found that anticipatory stress leads to more risky choices in the original GDT, but only if feedback is provided. In a modified version without feedback, participants under stress and in a control condition performed on a similar level (Starcke et al. 2008). It was concluded that task irrelevant emotions related to stress interfere with GDT performance by deteriorating the ability to process task relevant emotional feedback. The specific potential interference between GDT and executive versus emotional secondary tasks should be a topic of future studies.

In sum, the present large study observed that the simultaneous performance of a demanding working memory task causes impaired decision-making in the GDT. The findings support the hypothesis that decisions under risk, in contrast to decision under ambiguity rely on a cognitive (rational analytic) decision system. This system most likely relies on DLPFC function. The current results do not address the question if intuitive or analytical decisions lead to the best results (Evans and Over 2010; Marewski et al. 2010a, b) but demonstrate that under circumstances that offer explicit and stable rules system 2 seems to be involved. The results of the current study have thus both theoretical implications (in terms of dual-process theories and decision-making under risk, see above) and relevance for everyday life, because many decisions have to be made under suboptimal circumstances such as distraction by secondary tasks, time pressure, or stress.

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