

## BRIEF REPORT

### The role of emotions in complex problem-solving

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The assumption that positive affect leads to a better performance in simple cognitive tasks has become well established. We address the question whether positive and negative emotions differentially influence performance in complex problem-solving in the same way. Emotions were induced by positive or negative feedback in 74 participants who had to manage a computer-simulated complex problem-solving scenario. Results show that overall scenario performance is not affected, but positive and negative emotions elicit distinguishable problem-solving strategies: Participants with negative emotions are more focused on the seeking and use of information. We discuss methodological requirements for investigating emotion influences in complex and dynamic cognitive tasks.

When mathematician Andrew Wiles claimed to have solved Fermat's last theorem, his thorough attempt of proof was heavily criticised. But after an episode of distress he brought about a cast-iron proof of this century-old mathematical problem. The history of scientific endeavour often shows that feelings can influence our thinking in a beneficial or harmful way. This issue brings about further questions: Which emotions are beneficial to our problem-solving abilities and which emotions impair performance? In which tasks do emotions generally exert an influence and why?

The present study addresses the effects of emotions on problem-solving in complex and dynamic situations. In recent years, there has been growing interest in the role of affect in cognitive processes (e.g., Fiedler, 2001; Schwarz, 2000). Yet, most empirical

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studies have focused solely on naturally occurring mood states rather than using experimental manipulations of emotions, and have employed simple cognitive tasks rather than more complex problem-solving situations. We investigate whether the findings from studies on the influence of affect on simple cognitive tasks apply to experimentally induced emotions in a complex cognitive task.

### Theoretical rationale and research review

*Complex problem-solving: When you do not know what to do.* Complex problem-solving (CPS) is often contrasted with simple cognitive tasks along five criteria (Frensch & Funke, 1995; Funke, 2001): (1) complexity of the situation; (2) connectivity of variables; (3) dynamic development of the situation; (4) intransparency or opacity; and (5) polytelicity (pursue of multiple goals).

Simple problem-solving tasks, for example Duncker's (1945) candle task, Maier's (1930) nine-dot problem, or the famous Tower of Hanoi (e.g., Simon, 1975), require creative ingenuity and restructuring of given information. However, these tasks do not reflect the complexity of real-life situations. In response to this criticism Broadbent (1977) and Dörner (1980) proposed a new approach tailored to complex problems. Since then, CPS has been studied extensively by means of computer-simulated scenarios (e.g., *Lohhausen, Tailorshop, Biology Lab*), constructed to reflect characteristics of real-life problems (Dörner & Wearing, 1995; Funke, 2003). In the Lohhausen scenario, participants act as mayor of a small town and have to direct its economic and social situation. This complex task demands the acquisition and integration of information, the elaboration and attainment of goals, action-planning, decision-making, and self-management (Dörner, 1986).

*Emotions: When you know where your feelings come from.* Emotions are commonly understood as short-lived, intense phenomena that usually have a clear cognitive content and a salient cause that is accessible to the person experiencing the emotion (e.g., Clore, Schwarz, & Conway, 1994; Oatley & Johnson-Laird, 1987). Moods, on the other hand, are more global, diffuse, lack intentionality, are of longer duration and lower intensity (e.g., Ekman, 1994; Schwarz, 1990).

*Emotions and cognitive tasks: From simple to complex problem-solving.* Previous studies, employing a wide range of induction methods, demonstrate that moods and emotions differentially influence strategic approaches and solution quality of simple cognitive tasks. Positive affect leads to flexible and creative thinking (Fiedler, 2001; Isen, Daubman, & Nowicki, 1987), and also facilitates efficient decision-making in more complex environments (e.g., making a medical diagnosis; Isen, 2001). Individuals in a positive affective state are more likely to use heuristic top-down processing strategies, whereas negative affect facilitates careful bottom-up processing and a more systematic gathering of information (Bless & Fiedler, 1995; Hertel, Neuhof, Theuer, & Kerr, 2000; Schwarz, 1990, 2000).

Studies on CPS have concentrated on the influence of person variables, such as perceived emotional intelligence, emotional resilience, emotional reactivity, uncertainty, and anxiety as a trait (Dörner, 1998). The influence of stress, coping abilities, and achievement motivation on CPS has also been investigated (Hesse, Spies, & Lüer, 1983).

Results are inconsistent: Some studies found that emotional variables impair complex problem-solving, others detected no effect at all. The focus was almost solely on the *outcome* of complex problem-solving tasks and the influence of emotional variables on processing strategies was disregarded. Most importantly, emotional variables have not been induced experimentally.

## Overview of this study

We tested the influence of feedback-induced emotions on CPS. A computer-simulated scenario was used to test complex problem-solving performance and behaviour. Two hypotheses were tested. First, it is predicted that positive emotions, in contrast to negative emotions, lead to a better performance in the scenario. Second, positive and negative emotions should lead to different problem-solving behaviours: Positive emotions cause an intuitive, hypothesis-oriented approach, whereas negative emotions are associated with more detail-oriented, information-based behaviour.

## METHOD

### Measures

*Emotion induction.* A variety of induction techniques have been employed amongst which music and films have been most successful (Westermann, Spies, Stahl, & Hesse, 1996). We chose an induction method more relevant to the observers' task and elicited positive and negative emotions experimentally by giving false (positive or negative) feedback on performance twice throughout the experiment. The first feedback was administered by telling students a false score after they had completed the spatial-reasoning test, a subtest of the intelligence structure test 2000 (Intelligenz-Struktur-Test, I-S-T 2000; Amthauer, Brocke, Liepmann, & Beauducel, 1999). The second feedback was provided after half time of the computer-simulated scenario and was displayed automatically in a pop-up window, which informed participants about their position in a fictitious ranking (positive: "You are in position 12 out of 250 and are thus better than 95.2% of all participants"; negative: "You are in position 208 out of 250. That means that 83.2% of all participants have performed better than you").

*Emotion measures.* Emotions were measured seven times using a 14-item paper-and-pencil test. Participants had to mark a 10 cm line between the two poles *null* and *all pervasive* for each of 14 emotion adjectives (content, sad, excited, tense, confused, angry, anxious, surprised, enthusiastic, interested, calm, happy, ashamed, proud) that were put in random order. Emotion scores were derived from a factor analysis yielding three factors that retained all items. The three factors, as defined by high-loading items, were "negative emotions" (angry, anxious, ashamed, sad, confused), "positive emotions" (enthusiastic, happy, interested, calm, proud, content), and "arousal" (tense, excited, surprised). Three single emotion scores, representing the three factors, were calculated by aggregating participants' ratings (ranging from 0 to 10) on each item. These derived scores were used for further analysis.

*Complex problem-solving.* The computer-simulated scenario FSYS 2.0 (Wagener, 2001) was used in the current study.<sup>1</sup> Problem solvers had to manage a forest enterprise over a period of 50 months (simulation cycles) at a profit. They had to plant, grow, and cut down trees in five structurally equivalent forest partitions and maintain the wood's quality (e.g., fertilise grounds, do pest control). The scenario is based on Dörner's (1986) model of demands on problem solvers, and indicates strategies in different aspects of problem-solving behaviour additionally to the overall success in controlling the system. FSYS scales are organised in four dimensions: scenario performance (SP), quality of measures (QM), acquisition of information (AI), and self-management (SM). We focused on the dimensions SP, QM, and AI, and used the following scales as dependent variables:

- |                                    |  |
|------------------------------------|--|
| 1. Total capital earned (SP):      | Account balance plus value of forest after 50 cycles     |
| 2. Error prevention (QM):          | Correct dosage of measures (e.g., fertiliser, pesticide) |
| 3. Assigning of priorities (QM):   | Adequateness of decisions in goal conflicts              |
| 4. Efficiency of actions (QM):     | Total vs. partial achievement of subgoals                |
| 5. Early comprehension (QM):       | Time when each possible measure was ordered once         |
| 6. Early orientation (AI):         | Number of text elements accessed in first five cycles    |
| 7. Information before acting (AI): | Knowledge acquisition by reading texts before acting     |
| 8. Reading statistics (AI):        | Gaining overview of business by reading figures          |
| 9. Continuous surveying (AI):      | Continuity of inspection of forest partitions            |

High scores on any of the QM-scales, especially regarding early comprehension and prioritising, are assumed to be due to a more hypothesis-oriented behaviour, triggered by positive emotions. High scores on AI-scales are hypothesised to be related to a more information-oriented approach, triggered by negative emotions.

For the 90 minute duration of the test session, the program records and calculates the individual's performance data with regard to the overall profit yielded and behavioural components on the chosen scales that were later analysed separately.

*Additional measures.* Personal data (e.g., age, gender, subject of studies) were collected at the end of the experiment on a short standardised questionnaire that also asked for feedback on the experiment and any inconveniences that might have disrupted the procedure. No such influences were reported.

## Participants and procedure

Participants were 74 undergraduate and graduate students ( $n = 32$  female,  $n = 42$  male) mean age  $M = 24.6$  years ( $SD = 2.89$ ) of the University of Heidelberg, Germany. Participation was rewarded with partial credit for a course requirement or the gift of a book. The experiment took place in the Department of Psychology at the University of Heidelberg, Germany.

<sup>1</sup>The computer-simulated scenario FSYS 2.0 (Wagener, 2001) and related materials are available in English on CD-ROM. The scenario can be obtained on request from Dietrich Wagener, at the University of Mannheim, Lehrstuhl für Psychologie II, Schloss, D-68131 Mannheim, Germany; e-mail: dw@tnt.psychologie.uni-mannheim.de

Participants were randomly assigned to one of three treatment conditions (positive or negative feedback or a control group with no feedback), distributed equally with  $n = 24$  subjects in each of the treatment groups and  $n = 26$  subjects in the control group. The students were then tested individually. They first had to complete the spatial-reasoning test and were then given the written instructions for the computer-simulated scenario. Subsequently, emotions were induced by giving false feedback on the spatial-reasoning test score. Emotions were measured directly before and after the feedback. Next, participants worked on the scenario FSYS for 90 minutes. Every tenth cycle, a pop-up window instructed participants to complete another emotion questionnaire. After the 25th cycle, the second feedback was given automatically in a pop-up window. Emotions were measured immediately afterwards. The instructions and the procedure were highly standardised. At the end of the experiments, participants received veridical feedback about their performance in the spatial-reasoning test and scenario.

## RESULTS

*Manipulation check: How good was the emotion elicitation?* A series of ANOVAs were carried out on the three emotion scales (positive, negative, arousal) with feedback (positive, negative, control) as a factor for all time points in which emotions were measured. The emotion induction had a substantial effect on emotions in the expected direction only directly after the feedback was given. The second induction was more effective than the first. Treatment effects were more pronounced on positive and negative emotions than on arousal. Because we do not further analyse the possible effects of arousal on problem-solving performance, we refrain from reporting treatment effects on that scale here. Table 1 provides means and standard deviations of positive and negative emotion ratings at relevant time points with inferential statistics for participants who received positive, negative, or no feedback.

Positive emotions were significantly increased by the first positive, and decreased by the first negative feedback in comparison to the control group. The second feedback had an even more substantial effect on positive emotions. Negative emotions were changed accordingly only by the second feedback, but not by the first one. We conclude that the treatments were effective in eliciting emotions in the expected directions.

TABLE 1  
Means and standard deviations of emotion ratings directly after first and second feedback for three treatment groups ( $N = 74$ ) with  $F$ -test results

	<i>First treatment</i>				<i>Second treatment</i>			
	<i>Positive</i>	<i>Negative</i>	<i>Control</i>	<i>F(2,71)</i>	<i>Positive</i>	<i>Negative</i>	<i>Control</i>	<i>F(2,71)</i>
Positive	5.1 (2.4)	3.3 (1.7)	4.2 (1.7)	5.10**	5.4 (2.8)	2.5 (1.9)	3.7 (1.8)	10.38**
Negative	1.9 (1.8)	1.8 (1.4)	1.6 (1.5)	0.24	1.6 (1.3)	3.9 (2.6)	2.1 (1.7)	9.83***

\*\* $p < .01$ . \*\*\* $p < .001$ .

*Do emotions influence the outcome of complex problem solving?* To test the assumption that positive emotions facilitate and negative emotions impair scenario performance, a one-way ANOVA was carried out with feedback as a factor. Surprisingly, induced emotions do not differentially affect scenario performance (positive:  $M = 62.7$ ,  $SD = 23.8$ , negative:  $M = 63.2$ ,  $SD = 18.3$ , control:  $M = 60.8$ ,  $SD = 24.9$ ),  $F(2, 71) = 0.08$ , n.s.

*Creative vs. careful processing: Do positive and negative emotions direct strategies?* We further tested whether positive and negative emotions lead to different information-processing modes. A series of ANOVA was computed on QM-scales (quality of measures) and AI-scales (acquisition of information) with feedback as a factor. Table 2 provides performance data on the scenario scales and results of the omnibus  $F$ -tests for participants who received positive, negative, or no feedback.

Performance data do not differ significantly between treatment groups on any of the QM-scales and most AI-scales. Although negatively induced participants show higher means on AI-scales "Early orientation" and "Information before acting" relative to positively induced participants and controls, these differences do not reach statistical significance. The significant difference on the AI-scale "Continuous surveying", on the other hand, can be due to higher means in both treatment groups, as compared to controls.

Following the ANOVA, we conducted planned comparisons to precisely test the predictions with regard to the influence of positive emotions on QM-scales, and negative emotions on AI-scales. For QM-scales, a primary orthogonal contrast compared the positive induction group with the combined control and negative induction group

TABLE 2  
Means and standard deviations of performance on QM- and AI-scales in FSYS for three treatment groups ( $N = 74$ ) with results of the omnibus  $F$ -test, and two orthogonal contrasts<sup>a</sup>

FSYS-scales	Emotion induction			ANOVA	Contrasts	
					1	2
Error prevention (QM)	77.9 (14.3)	78.1 (10.7)	73.4 (16.9)	0.86	-0.62	-1.14
Assigning priorities (QM)	81.2 (8.8)	78.6 (10.6)	78.5 (9.1)	0.60	-1.09	-0.05
Efficiency of action (QM)	75.7 (6.8)	75.5 (6.6)	75.4 (7.9)	0.14	-0.16	-0.04
Early comprehension (QM)	84.2 (7.0)	83.1 (8.7)	86.7 (4.4)	1.79	0.40	1.84
Early orientation (AI)	39.3 (24.5)	56.0 (30.1)	40.2 (25.5)	2.99 <sup>†</sup>	-2.45*	0.11
Information before acting (AI)	50.9 (20.0)	65.0 (20.8)	57.3 (22.5)	2.68	-2.08*	1.08
Reading statistics (AI)	2.6 (3.4)	1.8 (2.4)	1.7 (2.7)	0.71	0.54	-1.07
Continuous surveying (AI)	61.3 (9.8)	62.2 (13.6)	54.2 (11.4)	3.57*	-1.53	-2.16*

<sup>a</sup> Contrasts 1 and 2 refer to two planned orthogonal contrasts. 1. *Main contrast: Positive* treatment group against combined negative treatment and control group (QM-scales, first four rows); *negative* treatment group against combined positive treatment and control group (AI-scales, last four rows). 2. *Follow-up contrast: negative* treatment group against control group (QM), *positive* treatment group against control group (AI).

\*  $p < .05$ . <sup>†</sup>  $p = .05$ .

(contrast 1), and a follow-up contrast compared the negative induction and control group (contrast 2). For AI-scales, the negative induction group was compared with the combined control and positive induction group (contrast 1), and the positive induction group with the control group (contrast 2). The results of the planned comparisons are presented in the last two columns of Table 2.

The planned comparison analyses did not affect our findings related to the QM-scales. However, the primary contrast was found to be significant for the AI-scales "Early orientation" and "Information before acting". These results suggest that negatively induced participants are considerably more thorough in their information search during the first five scenario cycles and are also more likely to gather information before acting. We found a significant follow-up contrast for the scale "Continuous surveying" between the positive induction group and the control group. An additional contrast between the negative induction group and the control group for this scale was also significant  $t(71) = -2.42, p < .05$ . This finding demonstrates that, in contrast to our predictions, the significant  $F$ -test result for this scale is due to higher means for both treatment groups, positive and negative, relative to the control group.

Overall, the significant effects of emotion induction on scenario performance and behaviour are rather selective. Note that conducting multiple  $F$ -tests might increase the chance of Type I error. However, we observed a significant tendency for negatively induced participants to be more information-oriented in their behaviour on more than one AI-scale. We therefore conclude that the significant effects in this study are meaningful.

## DISCUSSION

*Emotions do not influence complex problem-solving.* Positive and negative emotions did not differentially influence scenario performance. This unexpected result is inconsistent with most previous studies on simple problem-solving (e.g., Isen, 2001) and could originate from an inefficient treatment. However, the manipulation check demonstrated that both treatments elicited emotions in the expected direction. Three other issues are related to the question of treatment efficiency: (a) the intensity and duration of evoked emotions, (b) the influence of labelling state emotions, and (c) the attention that individuals pay to affective cues and the perceived relevance of emotions. Considering the first point, differences in emotions were only significant directly after the treatment was given. Induced emotions might not have lasted long enough to cause substantial differences in scenario performance. To the second point, labelling state emotions can reduce their impact on cognitive processes (Keltner, Locke, & Audrain, 1993). Emotions have been measured seven times throughout the experiment in order to gain information about the duration of the treatment effects and the stability of emotions. Based on the findings of Keltner et al. (1993), it is possible that the number of emotion questionnaires applied in this study caused an unwanted reduction of emotion influence on measurable cognitive processes. Concerning the third point, attention to emotions, Gasper and Clore (2000) found that the perception of the relevance of affective cues influences the use of emotions as a basis for judgement. According to the affect-as-information hypothesis (Schwarz, 1990), affect influences cognitive processes only when it is experienced as a source of relevant information. We presume that participants in our study valued emotional states as relevant, because emotions were induced by performance feedback directly relevant to the task. Yet, we did not control whether and how often individuals

actually attended to their emotions. We suspect that some students rarely noticed their feelings, let alone considered their feelings as a useful source of information.

Three conclusions can be drawn from these considerations. First, other emotion elicitation methods (i.e., inducement by music, pictures, or odours) might well prove to be more efficient, but they are only reasonable when they do not interfere with the requirements of the task. Alternatively, performance feedback could have been applied after each cycle. As problematic as this might be, a sustained treatment could also prohibit effects of scenario-inherent feedback (such as graphical process information) on performance. Second, the efficiency and duration of the treatment should be tested beforehand and questionnaires should be omitted in the main experiment to prevent a possible reduction of effects. Third, a variety of measures have been developed to assess individual differences in emotional attention and monitoring (e.g., Gasper & Clore, 2000; Otto, Döring-Seipel, Grebe, & Lantermann, 2001). We think it advisable to measure emotional attention and clarity as well as emotional stability as traits, especially in a demanding complex problem-solving situation. This leads to another explanation of our findings that is related to the nature of the task. The computer-simulated scenario FSYS constitutes a complex, challenging situation for the problem solver. Students might have regulated their emotions or focused more on the cognitive task than on their own feelings.

*Individuals with negative emotions are well-informed problem solvers.* There is a tendency showing that positive and negative emotions elicited distinguishable problem-solving strategies: As predicted by Fiedler's (2001) affect-cognition model, negative emotions led to a more detailed information search and to a more systematic approach to the scenario, especially during the first five cycles. The differences on the scale for early orientation in the first five months can be assumed to be a direct cause of the first treatment. As far as the effect of treatment on complex problem-solving *behaviour* is concerned, it can be concluded that Fiedler's model at least partly applies to emotions in CPS.

It can be inferred that emotions influence CPS on the level of information acquisition. One possible conclusion is that different emotion-induced strategies for CPS lead to the same result in the scenario FSYS. On the one hand, the problem solver has to be well informed and can thus benefit from negative emotions. On the other hand, quick and flexible decision-making is required—an approach that is basically elicited by positive emotion. It is probably the switching between different strategies (elicited by both, positive and negative emotions) that accounts for success in complex problem-solving. From this assumption we draw the conclusion that the dichotomy between positive and negative emotions does not necessarily lead to a classification of successful and unsuccessful problem solvers in complex tasks.

## Outlook

Many aspects of the results demonstrate that studying emotions within the research domain of CPS requires a different approach from analysing the effects of induced emotions on simple cognitive processes. Future research should concentrate on the formation and effect of different problem-solving strategies on behaviour in complex tasks rather than on emotion influences on overall success. Considering the attention to clarity and repair of emotions as moderating trait aspects (Otto et al., 2001) might enhance the



understanding of emotion influences on cognitive processes in complex tasks. Moreover, as the affect-cognition link is not unidirectional, we can assume that perceived success or failure in FSYS might have triggered emotions at any time throughout the scenario. Either, emotions have to be induced each cycle or postcognitive emotions have to be controlled by means of process-tracing methods. The comparison of precise emotions of the same valence has already been attempted (e.g., Lerner & Keltner, 2000), and further effort should be made to induce specific emotions purposefully.

Finally, Mellers and colleagues have offered a decision-affect theory of anticipated emotions that takes the emotional responses to the outcome of choice into account (e.g., Mellers, Schwartz, & Ritov, 1999). Decision-affect theory provides a descriptive account of actual emotions and would allow an examination of connections between anticipated emotions, strategy selection in CPS, and actual emotional responses. It might also be possible to differentiate between distinct emotions in order to answer the normative question whether people should actually employ emotions as a relevant parameter to guide their behaviour in complex situations.

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