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Brain and Cognition 60 (2006) 11–19
Brain and Cognition
www.elsevier.com/locate/b&c

How positive affect modulates cognitive control: The costs and benefits of reduced maintenance capability ☆

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Accepted 30 August 2005
Available online 10 October 2005

Abstract

Adaptive action in a constantly changing environment requires the ability to maintain intentions and goals over time and to flexibly switch between these goals in response to significant changes. Dreisbach and Goschke (2004) argued that positive affect modulates these antagonistic control demands in favor of a more flexible but also more distractible behavior. In the present paper, the author will present further evidence for the affective modulation of cognitive control: mild positive affect reduced maintenance capability in a simple cuing paradigm (the AX Continuous Performance Task) as compared to negative and neutral affect. This reduced maintenance capability results in costs when a to be maintained goal has to be executed and conversely results in benefits when a to be maintained goal unexpectedly changes. The data will be discussed with respect to existing theories on positive affect, cognitive control, and dopamine.

Keywords: Cognitive control; Positive affect; Dopamine

1. Introduction

One of the main challenges intelligent organisms are constantly confronted with is to dynamically adjust actions and thought to changing demands from the environment. On the one side the organism must be able to maintain intentions and goals over time and shield them against distraction. On the other side, the same organism must be flexible enough to switch from one thought or action to another whenever significant changes occur (Dreisbach & Goschke, 2004; Goschke, 2003; O'Reilly, Braver, & Cohen, 1999). Adaptive action thus requires a dynamic, context-dependent balance between maintaining and switching intentions. Goal of the present article is to present further evidence that this balance is modulated by positive affect (see also Dreisbach & Goschke, 2004; Dreisbach et al., 2005).

From behavioral studies there already exists ample evidence that positive affect as compared to negative or neutral affect has an influence on a broad range of cognitive processes (see Ashby, Isen, & Turken, 1999 for a review): positive affect enhances cognitive flexibility (Isen & Daubman, 1984; Isen, Niedenthal, & Cantor, 1992), increases verbal fluency (Philips et al., 2002), helps to overcome functional fixedness and improves problem solving (Greene & Noice, 1988; Isen, Daubman, & Nowicki, 1987), increases variety seeking among safe alternatives (Kahn & Isen, 1993), facilitates implicit judgments of semantic coherence (Bolte, Goschke, & Kuhl, 2003), and can reduce Stroop interference (Kuhl & Kazén, 1999). Taken together, these studies support the assumption that positive affect increases cognitive flexibility. Dreisbach and Goschke (2004), however, could show that the increased cognitive flexibility under positive affect happens at the cost of increased distractibility.

Studies using functional neuroimaging methods provide further evidence for the interaction of affect and higher

☆ I thank Thomas Goschke and Leigh Nystrom for helpful comments on an earlier version of this paper, and Susanne Diekelmann, Anka Irrgang, Kathrin Mueller, and Katja Schmidt for running the experiments.
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doi:10.1016/j.bandc.2005.08.003

cognition (e.g., Drevets & Raichle, 1998; Yamasaki, LaBar, & McCarthy, 2002; see also Dalgleish, 2004, for a review). For example, Yamasaki et al. (2002) used an oddball paradigm with emotional distracters and found the middle frontal gyrus activated by targets but deactivated by emotional distracters (positive and negative pictures) whereas the opposite activation pattern was found for the inferior frontal gyrus. In the same line, Drevets and Raichle (1998) report increased activation for emotion-related tasks in the amygdale, posteromedial orbital cortex, and the ventral anterior cingulate cortex (ACC) but decreased activation in these very regions for attentionally demanding cognitive tasks. These latter tasks conversely activated dorsolateral PFC and dorsal ACC, regions that were deactivated by induced or pathological emotional states. Taken together the results suggest a reciprocal relationship between dorsal and ventral PFC for cognition and emotion (cf. Yamasaki et al., 2002). Note, however, that in the Drevets and Raichle study only negative emotions (sadness, fear) were examined, whereas in the Yamasaki et al. study distracters of any emotional valence were included. It is therefore problematic to directly derive specific predictions for the effects of positive affect on cognitive control processes.

A detailed neuropsychological theory of positive affect has been developed by Ashby et al. (1999) and Ashby, Valentin, and Turken (2002). They assume that the cognitive and behavioral effects of positive affect are mediated by the neurotransmitter dopamine (DA). More specifically, the authors suggest that the enhanced cognitive flexibility under positive affect is mediated by DA release in the ACC. The assumed association between positive affect and DA gets support from studies showing that drugs that enhance dopaminergic activity like cocaine and amphetamine elevate mood (Beatty, 1995) whereas drugs that reduce dopaminergic activity (like the neuroleptic haloperidol) produce flattened affect (Hyman & Nestler, 1993).

Taken together, positive affect, presumably via mild increases in brain DA, seems to be well suited to mediate the balance between maintenance and flexibility. Derived from the general assumption that maintenance and flexibility impose antagonistic processing modes, positive affect, while increasing cognitive flexibility, should on the other side weaken the maintenance capability in working memory (WM). On first glance this assumption might seem to be at odds with findings from animal studies, showing that DA improves performance in simple WM tasks (Arnsten, Cai, Murphy, & Goldman-Rakic, 1994; Brozoski, Brown, Rosvold, & Goldman, 1979; Williams & Goldman-Rakic, 1995). However, empirical studies with humans on the effects of DA on WM performance yield ambiguous results and show that the influence of DA on WM performance in humans is highly complicated and only partly understood as its influence depends on several factors like dosage, time characteristics of the task, task information, and individual differences in WM capacity (see Kimberg & D'Esposito, 2003). In the light of these equivocal results, it seems even more necessary to collect behavioral data with paradigms that are sensitive to detect costs and benefits of improved cognitive flexibility.

To this end I used a modified version of the Continuous Performance Test (CPT, Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956), the AX-CPT (Servan-Schreiber, Cohen, & Steingard, 1996). This task seems to be well suited to examine processes of task maintenance because it predicts differential costs and benefits under the different task conditions in dependence of the maintenance capability. In the AX-CPT participants have to press a prespecified key (e.g., right key) to the probe "X" but only if it follows a designated cue "A" (see Fig. 1). Hence, the cue has to be maintained in WM until the probe appears. Whenever the X follows another letter (e.g., B) or whenever another letter than X follows the A (e.g., Y) a different key has to be pressed (e.g., left key). To impose a strong intentional set for target trials (AX), they will appear with 70% frequency whereas non-target trials will occur with 10% frequency each (BX, AY, BY where B represents any "non A" cue and "Y" represents any "non X" probe). Maintenance capability predicts different costs and benefits under the different non-target conditions. In the AY condition weak maintenance capability (as assumed under positive affect) predicts a *benefit* in terms of decreased RTs and/or fewer errors relative to strong maintenance. Accordingly, strong maintenance capability (as assumed under neutral or negative affect) would predict costs in terms of increased RTs and/or more errors relative to weak maintenance. The rationale is that the cue A predicts the probe X with 70% frequency. Hence, the stronger the cue A is maintained, the higher the costs if this expectation is hurt. At this point one might argue that improved performance on AY trials under positive affect might rather be due to enhanced cognitive flexibility that helps to rapidly switch the cognitive set when the A is followed by an unexpected Y. Therefore, it is important to take a look at the performance on BX and BY trials: on

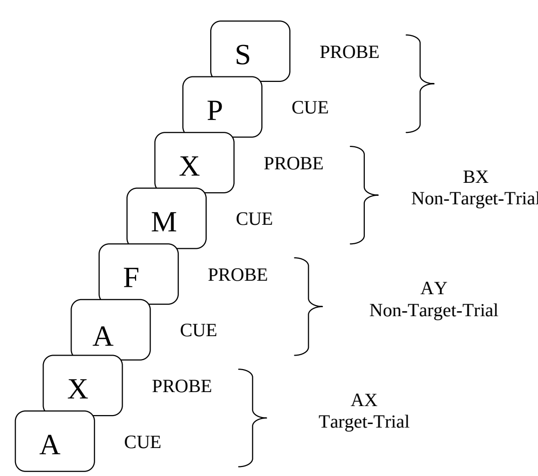

Fig. 1. The AX-CPT task with four different cue–probe-conditions as used in Experiment 1. Target trials appeared with 70% frequency and the non-target trials with 10% frequency each.

BX and BY trials weak maintenance (as assumed under positive affect) this time would predict *costs*, namely increased RTs and/or more errors relative to strong maintenance; accordingly, strong maintenance (as assumed under neutral or negative affect) would predict a *benefit*, namely decreased RTs and/or fewer errors as compared to weak maintenance. This prediction follows the same rationale: the appearance of the cue B already specifies the response key for the probe even before its appearance. Hence, the stronger the B is maintained, the easier the task performance of the probe will be. Additionally, in the BX condition (as compared to the BY condition) weak maintenance might lead to increased response competition because in 70% of the trials the X follows an A and thus has to be answered with a different response key than in the rare 10% cases when it follows the cue B. Hence, under positive affect reduced maintenance of the B might additionally increase RTs and/or error rates in the BX condition as compared to the BY condition.

Two experiments with the AX-CPT were run to test the assumption that positive affective picture stimuli weaken maintenance capability. For both experiments the predictions were that positive affect leads to better performance in the AY condition but to worse performance in the BX and BY conditions as compared to neutral and negative affect. Aside from the affect induction manipulation in Experiment 1 the CTI between cue and probe was varied; in Experiment 2 distracters between cue and probe were presented.

2. Experiment 1

2.1. Methods

2.1.1. Participants

In Experiment 1 78 undergraduates (54 female, $M = 23.09$, $SD = 3.73$, range 18–42) of the Dresden University of Technology participated for partial fulfillment of course credit or € 4. Participants signed informed consent and were debriefed after the session. Twenty-six participants were assigned to the negative, 26 to the neutral, and 26 to the positive picture group.

2.2. Materials and procedure

The letters A, X, B, D, E, F, G, M P, S, U, and Z served as stimuli. In target trials the letter A served as cue and the letter X served as probe. There were three kinds of non-target trials: In AY trials the cue A was followed by any letter except for X and A. In BX trials the cue could be any letter except for A and X and was followed by the probe X. And finally, in BY trials any letter except for A and X could serve as cue or as probe, respectively, with the only constraint that cue and probe were never identical (see Fig. 1). To set up a strong intentional set, target trials appeared with a frequency of 70% and non-target trials with a frequency of 10% each. Participants had to press the right key in response to target trials and the left key in response to non-target trials. Feedback was only given to errors in which case the intertrial interval was extended to 2000 ms.

As affect induction affective pictures derived from the International Affective Picture System were used (IAPS, Lang, Bradley, & Cuthbert, 1998). 10 neutral, 10 negative, and 10 positive pictures were selected, the same pictures that were used previously (Dreisbach & Goschke, 2004; see Appendix A for the numbers of the specific IAPS pictures). The mean ($\pm SE$) valence ratings (combined valence ratings for both sexes, Lang et al., 1998) from IAPS norms for the negative picture set were pleasant = 2.89 (1.66) and arousal = 5.25 (2.23), for the neutral pictures were pleasant = 4.9 (*SD* .95), arousal = 2.56 (*SD* 1.85), and for the positive picture set were pleasant = 7.68 (1.52) and arousal = 4.71 (2.38). The negative and neutral conditions were both necessary as control conditions because neutral pictures not only differ on the pleasantness scale but also on the arousal ratings (there are no neutral pictures that match the arousal scores of negative pictures). As for the negative pictures, they were matched to the mediate levels of the arousal scores of the positive pictures, which means that only moderately negative pictures were included (i.e., no victims of mutilation). As for the positive pictures, no sexually arousing pictures were chosen because these pictures are known to have differential effects on male and female participants. Pictures were presented in random, unpredictable order. Participants were informed at the beginning of the experiment about the occurrence of affective pictures. They were told that they should simply look at the pictures and that no questions concerning the pictures would be asked at the end of the experiment.

Each trial started with the presentation of a picture for 400 ms followed by a blank screen for 100 ms. The cue appeared for 300 ms, followed by a short (250 ms) or long (1250 ms) cue target interval (CTI). After that the probe was presented and remained on the screen until a response was given. The next trial started after a response stimulus interval (RSI) of 1250 ms (in the short CTI condition) or 250 ms RSI (in the long CTI condition). CTI was varied blockwise, whereas the different cue–probe-conditions were presented in an unpredictable randomized order within blocks. The CTI manipulation was included to examine time characteristics of the maintenance capability. Due to the simplicity of the task it was predicted that a long CTI would weaken task maintenance resulting in slower RTs and/or more errors.

The whole experiment consisted of two blocks of 100 trials each, resulting in 70 AX trials, and 10 trials of each remaining cue–probe-condition in every block. Half of the participants started with the long CTI and the other half with the short CTI.

Participants were asked to answer as quickly as possible while avoiding errors. The experiment started with a short introduction and 10 practice trials to explain the task.

2.3. Design

A 3 (affect: negative, neutral, positive picture) × 2 (CTI: 250 ms vs. 1250 ms) × 4 (cue–probe-condition: AX, AY, BX, BY) design was used. Affect was a between participants variable, CTI and cue–probe-condition were manipulated within participants. Response latencies and error rates served as dependent measures.

2.4. Results

2.4.1. RT data

Incorrect responses were excluded from the analysis. For each participant the median RT for each combined CTI and cue–probe-condition was computed.

Fig. 2 shows mean RTs as a function of CTI, cue–probe-condition, and affect. Upper panel shows the performance in the CTI 250 ms condition, lower panel in the CTI 1250 ms condition.

Obviously, participants generally had more problems in the AY condition as compared to any other cue–probe-conditions. And they were generally faster given a short CTI as compared to a long CTI. A 3 (affect) × 2 (CTI) × 4 (cue–probe-condition) analysis of variance (ANOVA) for repeated measures with affect as between subject factor consequently yielded significant main effects for the factor CTI, $F(1, 75) = 13.16$, $MSE = 9893.77$, $p < .001$, and cue–probe-condition, $F(3, 225) = 224.41$, $p < .001$ whereas the factor affect did not prove reliable ($p > .1$). A closer look at Fig. 2 reveals that participants in the positive affect group differ from the neutral and negative affect group on BX trials especially so given a long CTI. This observation is substantiated by the theoretically important interaction affect × cue–probe-condition, $F(6, 225) = 2.23$, $MSE = 5833.70$, $p < .05$. All further interactions were not significant (all $p > .3$). The prediction was that participants in the positive affect group as compared to negative and neutral affect show better performance on AY trials and worse performance on BX trials. This prediction is supported by a significant interaction AY vs. BX × positive vs. negative/neutral, $F(1, 75) = 4.24$, $MSE = 9015.49$, $p < .05$, whereas the interaction AY vs. BX × negative vs. neutral did not prove reliable ($p = .19$). Further analyses revealed that the interaction AY vs. BX × affect was mainly due to performance on BX trials: as predicted, in the positive affect group BX trials were answered slower than under neutral or negative affect, $F(1, 75) = 5.75$, $MSE = 30832.1$, $p < .02$. However, as is obvious from Fig. 2, predictions were not met on AY trials, RTs on AY trials were not faster in the positive picture group as compared to the neutral and negative picture group.

2.4.2. Error data

For every participant mean error percentage was computed for each combined CTI and cue–probe-condition.

Fig. 3 shows mean error rates as a function of CTI, cue–probe-condition, and affect. Upper panel represents the 250 ms CTI, lower panel the 1250 CTI condition. A 3

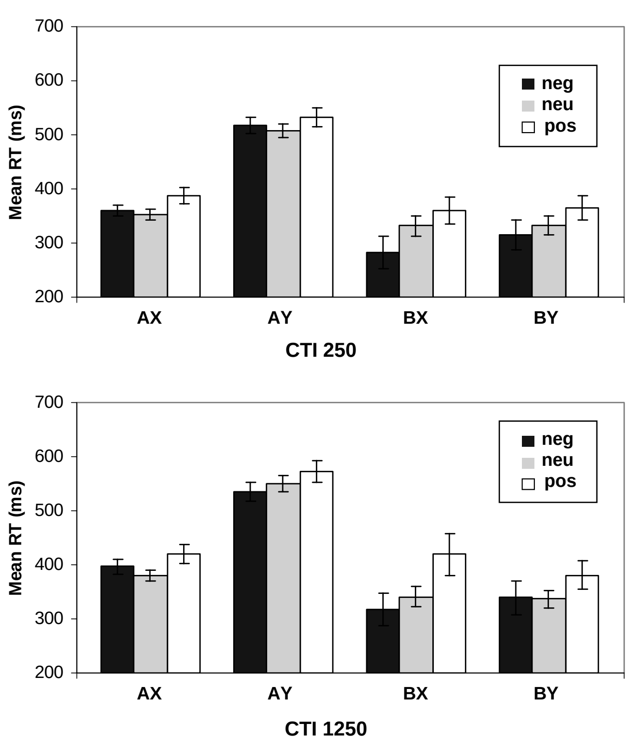

Fig. 2. Mean RTs in ms as a function of affect and cue–probe-condition in Experiment 1. Upper panel represents the CTI 250 condition and lower panel the CTI 1250 condition. Error bars represent one standard error of the mean.

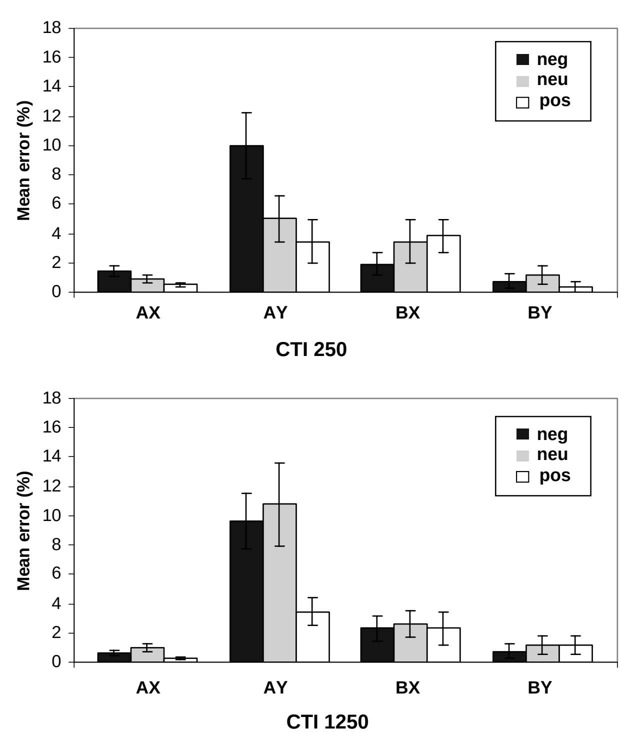

Fig. 3. Mean error rates (%) as a function of affect and cue–probe-condition in Experiment 1. Upper panel represents the CTI 250 condition and lower panel the CTI 1250 condition. Error bars represent one standard error of the mean.

(affect) × 2 (CTI) × 4 (cue–probe-condition) repeated measures ANOVA with affect as between subject factor yielded a significant main effect for the factor cue–probe-condition, $F(3, 225) = 31.68$, $MSE = 42.26$, $p < .001$. In contrast to the RT data, CTI did not prove reliable whereas affect only slightly failed statistical significance ($p = .068$). However, again the theoretically important interaction affect × cue–probe-condition proved reliable, $F(6, 225) = 3.42$, $MSE = 42.26$, $p < .01$. All further interactions were not significant (all $p > .1$). The interaction affect × cue–probe-condition is obviously due to the high error rate of the negative and neutral group in the AY condition as compared to the positive group. This observation is substantiated by a significant interaction AY vs. BX × positive vs. negative/neutral, $F(1, 75) = 7.23$, $MSE = 82.42$, $p < .01$. In accordance with the hypotheses error rates in the positive picture group were generally lower in the AY condition as compared to the negative and neutral group, $F(1, 75) = 7.43$, $MSE = 135.27$, $p < .01$.

3. Experiment 2

Experiment 2 followed the logic of Experiment 1 with one modification. Instead of varying the CTI, this time, distracters appeared between cue and probe. Again better performance under positive affect was hypothesized in the AY condition, and worse performance in the BX and BY condition as compared to neutral and negative affect.

3.1. Methods

3.1.1. Participants

Fifty-four undergraduates (32 female, $M = 23.2$, $SD = 3.3$, range 18–33) from the Dresden University of Technology participated for partial fulfillment of course credit or € 4. Participants signed informed consent and were debriefed after the session. Eighteen participants were assigned to the positive, negative, and neutral affect group, respectively. None of them had participated in the previous study.

3.2. Materials and procedure

Tasks, stimuli, materials, and procedure were exactly the same as in Experiment 2 with the following modification: after the presentation of the probe, the screen turned blank for 200 ms, followed by the consecutive presentation of three distracters for 300 ms each, and another 200 ms blank screen. Hence, the interval between cue and probe made up 1300 ms which is comparable to the long CTI condition in Experiment 1 (1250 ms). As distracter any letter from the stimulus pool except for A and X could appear. To facilitate the discrimination between cue, probe, and distracter, the cue and probe were presented in red whereas the distracters were presented in black. Distracters appeared randomized with the only constraint that no immediate repetitions were allowed. Participants were informed that only the red letters were important to execute the task. Again, participants received two blocks of 100 tasks each. Because no factor was manipulated between blocks (as compared to the CTI manipulation in Experiment 1) the data points for each condition this time were twice the size of Experiment 1, therefore allowing for the smaller overall sample size.

3.3. Design

A 3 (affect: positive, negative, neutral picture) × 4 (cue–probe-condition: AX, AY, BX, BY) design was used. Affect was manipulated between participants whereas the cue–probe-condition was manipulated within participants.

3.4. Results

3.4.1. RT data

Data were collapsed over the two experimental blocks. Incorrect responses were again excluded from the analysis. For each participant the median RT for each cue–probe-condition was computed.

Fig. 4 (upper panel) shows mean RTs as a function of affect and cue–probe-condition. Apparently, participants in the positive affect group were slower in the BX and BY condition as compared to the neutral and negative affect group. And they showed even a slight RT benefit in the AX and AY condition. A 3 (affect) × 4 (cue–probe-condition) repeated measures ANOVA with affect as between subjects factor consequently yielded a significant main effect cue–probe-condition, $F(3, 153) = 70.74$, $MSE = 7395.65$,

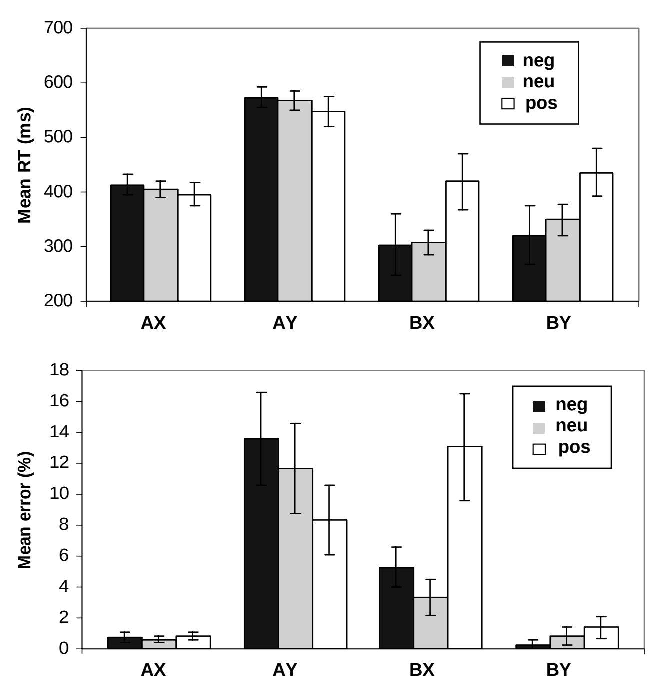

Fig. 4. Mean RTs in ms (upper panel) and mean error rates in percentage (lower panel) as a function affect and cue–probe-condition in Experiment 2. Error bars represent one standard error of the mean.

$p < .001$, and a significant interaction affect × cue–probe-condition, $F(6, 153) = 4.44$, $MSE = 7395.65$, $p < .001$. Additional analysis showed the theoretically important interaction positive vs. negative/neutral × AY vs. BX, $F(1, 51) = 10.04$, $MSE = 11147.73$, $p < .01$. This interaction is mainly driven by the fact that, as predicted, RTs on BX trials are slower in the positive picture group as compared to the negative and neutral picture group, $F(1, 51) = 4.06$, $MSE = 37830.1$, $p < .05$.

3.4.2. Error data

Fig. 4 (lower panel) depicts mean error rates in the positive, neutral, and negative affect group under the different cue–probe-conditions. The results sharpen those of Experiment 1 in that under positive affect error rates are lower on AY trials but at the same time remarkably higher on BX trials than under negative affect.

Consequently, a 3 (affect) × 4 (cue–probe-condition) repeated measures ANOVA with affect as between subjects variable yielded a significant main effect of the cue–probe-condition, $F(3, 153) = 24.06$, $MSE = 59.15$, $p < .001$, as well as a significant interaction affect × cue–probe-condition, $F(3, 153) = 3.11$, $MSE = 59.15$, $p < .01$ whereas the factor affect was far from reliable ($p = .36$). As predicted, error rates in the positive picture group were lower on AY trials but higher on BX trials as compared to negative and neutral affect, an observation that is substantiated by the significant interaction positive vs. negative/neutral × AY vs. BX, $F(1, 51) = 8.13$, $MSE = 125.72$, $p < .01$.

4. Discussion of Experiments 1 and 2

Purpose of the presented experiments was to test the hypothesis that maintenance capability is modulated by positive affect. It was predicted that positive affect weakens maintenance capability, which should worsen performance in the BX and BY conditions on the one side but improve performance in the AY condition as compared to negative and neutral affect on the other. The results presented here in general support the hypotheses. Lowered maintenance capability under positive affect was accompanied by *poorer* performance on BX and BY trials (increased RTs in Experiment 1, especially in the long CTI condition, and additionally increased error rates on BX trials in Experiment 2). Conversely, the reduced maintenance capability under positive affect led to *better* performance on AY trials (less errors in Experiments 1 and 2). Obviously, the benefits of positive affect on AY trials only materialized in the error data but not in the RT data. One possible reason is that the high frequency occurrence of AX trials imposed such a strong intentional set that even under low maintenance capability as assumed under positive affect the occurrence of the A automatically set an expectation for the target X, thereby leading to some kind of time consuming distraction or surprise when another letter than an X occurred. This would also explain why the performance on AX trials does not differ between the different affect groups. However, the lower error rate in the positive affect group in the AY condition suggests that under positive affect participants either did not specifically prepare the wrong response key or that they were flexible enough to adjust to the unexpected task demands. Likewise, the higher error rates in the neutral and negative affect group indicate that participants were either not flexible enough to adjust to the current unexpected task demands or, at least in some cases, had already prepared the wrong response in the interval between A and Y.

In Experiment 1, in contrast to the predictions, the interaction CTI × affect proved not significant. Reduced maintenance capability in the positive affect group should have materialized especially given a long CTI. One possible reason could be that—given the simplicity of the task—a long CTI generally led to increased RTs as indicated by the significant main effect CTI, irrespective of the affect induction manipulation.

Introducing distracters between cue and target in Experiment 2 obviously increased maintenance demands as became evident from the more pronounced affect effects. In contrast to Experiment 1 the reduced maintenance capability under positive affect not only increased RTs on BX and BY trials but also remarkably increased the error rate on BX trials but not on BY trials. Why does the assumed reduced maintenance of the cue B under positive affect affect RT data in both, the BX and the BY condition but the errors of only the BX condition? This seemingly discrepant result can be solved if one takes into account that the cue B already led to the specific preparation of the non-target response key in the negative and neutral affect group but not so in the positive affect group. This explains the faster RTs in the negative and neutral affect group on BX and BY trials and slower RTs in the positive affect group, respectively. However, as soon as the probe X appeared, those who had not already prepared the non-target response key, as was presumably the case in the positive affect group, were more error prone to press the wrong response key, because in most of the cases, the X was preceded by an A and thus had to be answered with a different key. On BY trials, however, the positive affect group was no more error prone than the neutral or negative affect group, because, even with reduced maintenance of the cue B, the Y was unequivocally mapped to the non-target key. Hence, even though the reduced maintenance of the probe B under positive affect results in slower RTs whether it is followed by an X or by a Y, it only results in increased error rates when the B is followed by an X because on BY trials you do not need to know what preceded the target to answer it correctly. Together with the performance on AY trials the results thus suggest that the reduced maintenance capability under positive affect goes along with reduced response preparation as compared to neutral or negative affect. However, from behavioral data alone this interpretation cannot unequivocally be driven and will have to be addressed in future research.

To sum up, increasing the maintenance demands by presenting distractors within the CTI interval in Experiment 2 made the differences in maintenance capability under positive affect as compared to neutral or negative affect more evident. One further result of Experiment 2, worth being mentioned here, is that under distraction conditions participants in the positive affect group made far more errors than in the standard condition in Experiment 1 (5.89 and. 1.92%, respectively). Hence, the introduction of distracters obviously had detrimental effects on maintenance capability and thereby generally disturbed task performance in the positive affect group. This perfectly fits with results of a recent study (Dreisbach & Goschke, 2004) where the authors showed that positive affect goes along with increased distractibility.

5. General discussion

Purpose of the present study was to collect further evidence for the assumption that positive affect plays an important role in the modulation of the balance between maintenance and flexibility. The theoretical basis for conducting these experiments is derived from the general framework that flexibility and stability impose antagonistic control demands (Dreisbach & Goschke, 2004; Dreisbach et al., 2005; Goschke, 2003). Hence, given the broad empirical evidence that positive affect promotes cognitive flexibility (e.g., Bolte et al., 2003; Greene & Noice, 1988; Isen & Daubman, 1984; Isen et al., 1987, 1992; Kahn & Isen, 1993; Kuhl & Kazén, 1999; Philips et al., 2002), it was assumed that positive affect then should impair maintenance capability. Overall, the presented data support the hypotheses. It was shown that mild positive affect, induced via short presentation of affective picture stimuli, actually led to better performance (namely, less errors) when an expectation was hurt (like in AY trials), suggesting that the maintenance of the cue and the appropriate preparation of the target was not as strong as under negative or neutral affect. On the other side, under conditions where strong maintenance should facilitate performance (as in BX and BY trials) positive affect was found to impair performance as compared to negative affect. This data pattern of costs and benefits due to weak maintenance capability underlines the statement that there is no such thing like an ideal processing mode, but that it strongly depends on the current task demands whether a more flexible or a more stable processing mode is adaptive. A more flexible behavior is adaptive whenever we are confronted with unexpected events whereas a more stable behavior is required when intentions have to be maintained over time and shielded against distraction. The reduced maintenance capability under positive affect was adaptive only when unexpected events occurred but maladaptive in all other cases.

It should be mentioned that the AX task is not really challenging the cognitive system. More demanding tasks might have forced participants, even under positive affect, to stay focused and concentrated. Therefore, the conclusion that positive affect decreases the maintenance capability so far is limited to simple task demands.

The presented data fit nicely with neuropsychological theories of positive affect, DA, and cognitive control (Ashby et al., 1999, 2002; Cohen, Braver, & Brown, 2002). Though differing in the details, both research groups assume that DA promotes the modulation of cognitive control and fosters the flexible updating of WM. Applied to the data presented here, the short presentation of positive affective pictures might have led to mild DA increases in the prefrontal cortex (Cohen et al., 2002) or in the anterior cingulate cortex (Ashby et al., 2002) and thereby impaired the maintenance capability. The data presented in this article show that positive affect, presumably via mild increases in DA activity in prefrontal brain areas improved cognitive flexibility but at the same time incurred a cost due to reduced maintenance capability. Of course it is impossible to conclude from behavioral data alone whether indeed increased DA activity is the underlying mechanism that produces the observed effects of positive affect. However, in a recent study using the same paradigm as Dreisbach and Goschke (2004), more direct evidence was found for the assumption that the effects of positive affective picture stimuli are driven by central dopaminergic activity (Dreisbach et al., 2005): in this study spontaneous eye-blink rate as a functional marker of dopaminergic activity (Elsworth et al., 1991) and a dopamine receptor gene polymorphism (DRD4 exon III polymorphism; Oak, Oldenhof, & Van Tol, 2000) was included, making it possible to divide the participants in a high and low DA activity group. In the absence of any affect manipulation, high blinkers indeed showed the same data pattern as the positive affect group in the original study, that is, increased cognitive flexibility along with increased distractibility (Dreisbach & Goschke, 2004), whereas low blinkers behaved like those in the original neutral condition. This pattern of results was even potentiated for carriers of a specific genetic variant, the DRD4 7-repeat polymorphism. Even though correlational in nature, these results further support the assumption that the effects of positive affect are mediated by central dopaminergic activity.

From a neuropsychological perspective, it is hard to imagine that positive affect, and thus dopaminergic activity, is the only mechanism that mediates the balance between a flexible and stable processing mode. It certainly would not be adaptive if the cognitive system solely depended on affective states to adjust the processing mode to current task demands. Actually, there already exists empirical evidence that further neurotransmitters play an important role in the modulation of cognitive control. In this respect, one recent theory emphasizes the role of the locus coeruleus (LC) with its neurotransmitter norepinephrine (NE) (Aston-Jones, Rajkowski, & Cohen, 1999; Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994a; Rajkowski, Kubiak, & Aston-Jones, 1994; Usher, Cohen, Servan-Schreiber, Rajkowski, & Aston-Jones, 1999). From animal studies with monkeys the authors conclude that a phasic LC-NE activity (with its broad projections throughout the cortex, hippocampus, and further subcortical areas) promotes focused selective attention whereas a tonic LC-NE mode promotes behavioral flexibility. From a cognitive perspective these observations are interesting because the LC activity also seems to modulate the sleep–wake-cycle and—more importantly—arousal in humans. Because affective states are always accompanied by changes in the arousal level, it is important to note that the increased cognitive flexibility observed under positive affect cannot be attributed to increased arousal because no improvement in cognitive flexibility was found for higher arousal states alone (e.g., Isen et al., 1987). Arousal, in general, is rather thought to have quite unspecific effects on cognition in that it increases the likelihood of the dominant response (Berlyne, 1967; Easterbrook, 1959). Hence, future research will have to further investigate whether specific arousal states can also have differential effects on cognition in humans as the LE-NE theory by Aston-Jones and colleagues suggests (see Aston-Jones & Cohen, 2005, for a review). This, however, might be more complicated than it sounds, because unitary concepts of arousal have proved to be little useful (for a discussion on this topic see Robbins, 1997).

Another open question concerns the role of negative affect and its underlying neuropsychological mechanisms on cognitive control. As mentioned in Section 1, imaging studies found reciprocal suppression of brain activation during emotional (especially negative emotional) and cognitive processes (Drevets & Raichle, 1998; Yamasaki et al., 2002). However, in the experiments presented here, no robust differences between the negative and neutral affect group emerged, which of course might be due to the fact that only moderately negative pictures were used. However, in a recent study, Gasper (2003) compared performance in a classic mental set task (Luchins, 1942; cf. Gasper, 2003) between sad, neutral, and happy mood, and found that people in a sad mood more strongly relied on the mental set as compared to people in a neutral or happy mood.[1] This result can easily be interpreted in terms of enhanced maintenance capability under sad mood and thus is in line with the data of the negative affect group in the current study. On the other side, there exists also empirical evidence that points into the opposite direction. For example, Gray (1999) found evidence that under threat-related negative affect people preferred choices that had better short-term but poorer long-term consequences suggesting that the maintenance of the (better) long-term consequence was impaired. Hence, it would be premature to draw the conclusion that negative affect simply has the opposite effects on cognitive processes as compared to positive affect. First of all, it seems that different negative affective states (like sadness, anger, and fear) might have less in common than positive affective states (like for example joy, love, and happiness) making it difficult to talk about negative affect as a unitary concept. Second, positive and negative affect rely on independent neural mechanisms (George et al., 1995) and might even be localized in different cerebral hemispheres (Davidson, 1992; Henriques & Davidson, 1991). And finally, with respect to the assumed link between positive affect and brain DA, the reduction of DA does not produce negative but rather flattened affect (Hyman & Nestler, 1993) which might be better described in terms of the absence of any affect. Hence, even though negative affect might have an effect on cognitive control, it clearly is not simply the opposite effect with the corresponding underlying opposite neurobiological mechanisms.

[1] One should of course bear in mind that it is problematic to compare studies where mood induction procedures were used that led to enduring changes in conscious mood with studies that use short presentation of affective stimuli, rather serving as "reward signals" that are not leading to changes in conscious mood.

6. Conclusion

Adaptive action in a constantly changing environment requires the ability to maintain intentions and goals over time on the one side and to flexibly switch between these goals on the other. The data presented in this article support the assumption that mild positive affect mediates the balance between these antagonistic control demands (see also Dreisbach & Goschke, 2004; Goschke, 2003) in that the increased flexibility under positive affect, often reported in the literature, is accompanied by impaired maintenance capability.

Appendix A

Numbers of affective picture stimuli (Lang et al., 1998)

Neutral: 7000, 7002, 7004, 7006, 7009, 7010, 7020, 7025, 7030, 7034.
Positive: 1440, 1463, 1710, 2050, 2057, 2058, 2250, 2311, 2341, 2345.
Negative: 1120, 2120, 2800, 6830, 9041, 9102, 9280, 9290, 9470, 9560.

References

Arnsten, A. F., Cai, J. X., Murphy, B. L., & Goldman-Rakic, P. S. (1994). Dopamine D1 receptor mechanisms in the cognitive performance of young adult and aged monkeys. *Psychopharmacology, 116*, 143–151.

Ashby, F. G., Isen, A. M., & Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*(3), 529–550.

Ashby, F. G., Valentin, V. V., & Turken, A. U. (2002). The effects of positive affect and arousal on working memory and executive attention: Neurobiology and computational models. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behaviour*. Amsterdam: John Benjamins.

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28*, 403–450.

Aston-Jones, G., Rajkowski, J., & Cohen, J. D. (1999). Role of locus coeruleus in attention and behavioral flexibility. *Biological Psychiatry, 46*, 1309–1320.

Aston-Jones, G., Rajkowski, J., Kubiak, P., & Alexinsky, T. (1994a). Locus coeruleus neurons in the monkey are selectively activated by attended stimuli in a vigilance task. *Journal of Neuroscience, 14*, 4467–4480.

Beatty, J. (1995). *Principles of behavioral neuroscience*. Dubuque, IA: Brown & Benchmark.

Berlyne, D. E. (1967). Arousal and reinforcement. In D. Levine (Ed.), *Nebraska symposium on motivation: Vol. 15. Current theory & research in motivation* (pp. 1–110). Lincoln: Universtiy of Nebraska Press.

Bolte, A., Goschke, T., & Kuhl, J. (2003). Emotion and intuition: Effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science*.

Brozoski, T. J., Brown, R. M., Rosvold, H. E., & Goldman, P. S. (1979). Cognitive deficit aused by regional depletion of dopamine in prefrontal cortex of rhesus monkey. *Science, 205*, 929–932.

Cohen, J. D., Braver, T. S., & Brown, J. W. (2002). Computational perspectives on dopamine function in prefrontal cortex. *Current Opinion in Neurobiology, 12*, 223–229.

Dalgleish, T. (2004). The emotional brain. *Nature Reviews Neuroscience, 5*, 582–589.

Davidson, R. J. (1992). Emotion and affective style: Hemispheric substrates. *Psychological Science, 3*, 39–43.

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: Reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K.-P., et al. (2005). Dopamine and cognitive control: The influence of spontaneous eye-blink rate and dopamine gene polymorphisms on perseveration and distractibility. *Behavioral Neuroscience, 119*, 483–490.

Drevets, W. C., & Raichle, M. E. (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: Implications for interactions between emotion and cognition. *Cognition and Emotion, 12*, 353–385.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*, 183–201.

Elsworth, J. D., Lawrence, M. S., Roth, R. H., Taylor, J. R., Mailman, R. B., Nichols, D. E., et al. (1991). D-sub-1 and D-sub-2 dopamine receptors independently regulate spontaneous blink rate in the vervet monkey. *Journal of Pharmacology and Experimental Therapeutics, 259*, 595–600.

Gasper, K. (2003). When necessity is the mother of invention: Mood and problem solving. *Psychological Science, 39*, 248–262.

George, M. S., Ketter, T. A., Parekh, P. I., Horwitz, B., Herscovitch, P., & Post, R. M. (1995). Brain activity during transient sadness and happiness in healthy women. *American Journal of Psychiatry, 152*, 341–351.

Goschke, T. (2003). Voluntary action and cognitive control from a cognitive neuroscience perspective. In S. Maasen, W. Prinz, & G. Roth (Eds.), *Voluntary action. An issue at the interface of nature and culture* (pp. 49–85). Oxford: Oxford University Press.

Gray, J. (1999). A bias toward short-term-thinking in threat-related negative emotional states. *Personality and Social Psychology Bulletin, 25*, 65–75.

Greene, T. R., & Noice, H. (1988). Influence of positive affect upon creative thinking and problem solving in children. *Psychological Reports, 63*, 895–898.

Henriques, J. B., & Davidson, R. J. (1991). Left frontal hypoactivation in depression. *Journal of Abnormal Psychology, 100*, 535–545.

Hyman, S. E., & Nestler, E. J. (1993). *The molecular foundations of psychiatry*. Washington, DC: American Psychiatric Press.

Isen, A. M., & Daubman, K. A. (1984). The influence of affect on categorization. *Journal of Personality and Social Psychology, 47*, 1206–1217.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology, 52*, 1122–1131.

Isen, A. M., Niedenthal, P., & Cantor, N. (1992). The influence of positive affect on social categorization. *Motivation and Emotion, 16*, 65–78.

Kahn, B. E., & Isen, A. M. (1993). Variety seeking among safe, enjoyable products. *Journal of Consumer Research, 20*, 257–270.

Kimberg, D. Y., & D'Esposito, M. (2003). Cognitive effects of the dopamine receptor agonist pergolide. *Neuropsychologia, 41*, 1020–1027.

Kuhl, J., & Kazén, M. (1999). Volitional facilitation of difficult intentions: Joint activation of intention memory and positive affect removes Stroop interference. *Journal of Experimental Psychology: General, 128*, 382–399.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). *International affective picture system (IAPS): Technical manual and affective ratings*. Gainsville, FL: University of Florida Center for Research in Psychophysiology.

Luchins, A. S. (1942). Mechanization in problem solving: The effect of Einstellung. *Psychological Monographs, 54*, 1–95.

Oak, J. N., Oldenhof, J., & Van Tol, H. H. M. (2000). The dopamine D receptor: One decade of research. *European Journal of Pharmacology, 405*, 303–327.

O'Reilly, R. C., Braver, T. S., & Cohen, J. D. (1999). A biologically-based computational model of working memory. In A. Miyake & P. Shah (Eds.), *Models of Working Memory: Executive Control* (pp. 375–411). New York: Cambridge University Press.

Phillips, L. H., Bull, R., Adams, E., & Fraser, L. (2002). Positive mood and executive functions: Evidence from stroop and fluency tasks. *Emotion, 2*, 12–22.

Rajkowski, J., Kubiak, P., & Aston-Jones, G. (1994). Locus coeruleus activity in monkey: Phasic and tonic changes are associated with altered vigilance. *Brain Research Bulletin, 35*, 607–616.

Robbins, T. W. (1997). Arousal systems and attentional processes. *Biological Psychology, 45*, 57–71.

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology, 20*, 343–350.

Servan-Schreiber, D., Cohen, J. D., & Steingard, S. (1996). Schizophrenic deficits in the processing of context: A test of a theoretical model. *Archives of General Psychiatry, 53*, 1105–1112.

Usher, M., Cohen, J. D., Servan-Schreiber, D., Rajkowski, J., & Aston-Jones, G. (1999). The role of locus coeruleus in the regulation of cognitive performance. *Science, 283*, 549–554.

Williams, G. V., & Goldman-Rakic, P. S. (1995). Modulation of memory fields by dopamine D1 receptors in prefrontal cortex. *Nature, 376*, 572–575.

Yamasaki, H., LaBar, K. S., & McCarthy, G. (2002). Dissociable prefrontal brain systems for attention and emotion. *Proceedings of the National Academy of Sciences of the United States of America, 99*, 11447–11451.