

The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control

Kerstin Fröber · Gesine Dreisbach

Published online: 22 March 2014
© Psychonomic Society, Inc. 2014

Abstract Growing evidence suggests that positive affect and reward have differential effects on cognitive control. So far, however, these effects have never been studied together. Here, the authors present one behavioral study investigating the influences of positive affect and reward (contingent and non-contingent) on proactive control. A modified version of the AX-continuous performance task, which has repeatedly been shown to be sensitive to reward and affect manipulations, was used. In a first phase, two experimental groups received either neutral or positive affective pictures before every trial. In a second phase, the two halves of a given affect group additionally received, respectively, performance-contingent or random rewards. The results replicated the typical affect effect, in terms of reduced proactive control under positive as compared to neutral affect. Also, the typical reward effects associated with increased proactive control were replicated. Most interestingly, performance-contingent reward counteracted the positive affect effect, whereas random reward mirrored that effect. In sum, this study provides first evidence that performance-contingent reward, on the one hand, and positive affect and performance-noncontingent reward, on the other hand, have oppositional effects on cognitive control: Only performance-contingent reward showed a motivational effect in terms of a strategy shift toward increased proactive control, whereas positive affect alone and performance-noncontingent reward reduced proactive control. Moreover, the integrative design of this study revealed the vulnerability of positive affect effects to motivational manipulations. The results are

discussed with respect to current neuroscientific theories of the effects of dopamine on affect, reward, and cognitive control.

Keywords Cognitive control · Emotion · Reward · Dopamine

Positive affect arises in a variety of situations—for instance, being woken up by the sunlight after a long period of foggy days, winning €100 by being the 100,000th customer of the local hardware store, or getting a €100 bonus for above-average performance as a piece-worker. These examples show that exposure to positive stimuli, receiving an unexpected random reward, or earning a performance-contingent reward is associated with the elicitation of positive affect. Exactly this obvious relationship between positive affect and reward has been the basis of a very influential theory—namely, the neuropsychological theory of positive affect by Ashby, Isen, and Turken (1999; see also Ashby, Valentin, & Turken, 2002). Because reward effects are mediated by dopamine activity (see, e.g., Schultz, 1992), the authors argued that positive affect effects might also be mediated by dopamine. More specifically, they assumed that positive affect increases dopamine release from the ventral tegmental area into anterior cingulate cortex and prefrontal cortex, and this mechanism supposedly modulates cognitive control, in terms of enhanced cognitive flexibility, by facilitating selection of and switching between cognitive sets. That is, positive affect—irrespective of its origin—has long been assumed to have an important influence on the regulation of cognitive control. But is it really justified to treat positive affect from different sources as being functionally the same?

On the one side, and on the basis of the intuitional relationship between positive affect and reward along with supporting theories like the neuropsychological theory of positive affect (Ashby et al., 1999; Ashby et al., 2002), it is not surprising that

Electronic supplementary material The online version of this article (doi:10.3758/s13415-014-0259-x) contains supplementary material, which is available to authorized users.

K. Fröber (✉) · G. Dreisbach
Department of Psychology, University of Regensburg,
Universitätsstr. 31, 93053 Regensburg, Germany
e-mail: kerstin.froeber@psychologie.uni-regensburg.de

the existing literature on affective modulations of cognitive control often ignored the difference between affect and reward manipulations. On the other side, it seems just as intuitive to assume that positive affect as a result of performance-contingent reward might rather have a motivational (as opposed to an affective) influence on behavior. And indeed, two recent reviews (Chiew & Braver, 2011; Dreisbach & Fischer, 2012) challenged the idea of a common mechanism of positive affect and reward effects on the basis of a growing number of diverging results on affect–cognition interactions. One group of studies, all investigating processes of proactive and reactive control (Braver, 2012; Braver, Gray, & Burgess, 2007), found opposing effects for positive affect and reward (Chiew & Braver, 2013; Dreisbach, 2006; Fröber & Dreisbach, 2012; Jimura, Locke, & Braver, 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011; van Wouwe, Band, & Ridderinkhof, 2011). Likewise, another group of studies, investigating processes of sequential conflict adaptation (i.e., reduced response conflict on trials following conflict trials), as well found opposing effects for positive affect and random reward on the one side and performance-contingent reward on the other (Braem, Verguts, Roggeman, Notebaert, & Roggeman, 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011; van Steenbergen, Band, & Hommel, 2009, 2010, 2012; van Wouwe et al., 2011). It thus seems that although reward and positive affect are closely related, both have dissociable effects on cognitive control—the former being motivational and the latter affective. However, since affect and reward have never been studied together, it is still hard to judge which results can actually be attributed to the alleged difference of reward and affect effects, and which are simply due to other procedural differences between studies and paradigms.

In the present study, we will focus on how positive affect and reward influence cognitive control strategies within a single paradigm. According to the dual mechanisms of control (DMC) framework (Braver, 2012; Braver et al., 2007), two control strategies, namely proactive—that is, preparatory—control and reactive—that is, just-in-time—control, can be differentiated. In the DMC, preparatory control is aimed at preventing conflict and optimizing task performance by sustained activation of task relevant information, whereas reactive control is a less effortful strategy that works as a late correction mechanism whenever a conflict actually occurs. Empirical results so far indicate that reward increases proactive control strategies (Chiew & Braver, 2013; Jimura et al., 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011), whereas positive affect is associated with reduced proactive control and/or increased reactive control (Dreisbach, 2006; Fröber & Dreisbach, 2012; van Wouwe et al., 2011). To illustrate, we will now shortly review several studies all using the AX-continuous performance task (AX-CPT; Servan-Schreiber, Cohen, & Steingard, 1996), a paradigm that we also used in the present study.

The AX-CPT is a context processing task especially suited to investigate changes in the use of proactive and reactive control (cf. Braver, 2012; Braver et al., 2007). Therein, specific cue–probe sequences require target or nontarget responses: Target trials are specified as cue “A” followed by probe “X” (AX trials), whereas nontarget trials can be AY (target cue, nontarget probe), BX (nontarget cue, target probe), or BY trials (nontarget cue, nontarget probe). AX sequences appear with a frequency of 70%, resulting in a high expectation for target trials following the cue “A” and strong associations between the probe “X” and target responses. A proactive control strategy in this task means strong maintenance of the cue for in advance response preparation, which should result in costs in AY trials, in which the cue-triggered expectation is violated, and benefits in B-cue trials, in which the cue unequivocally predicts the correct response. Conversely, reactive control should result in benefits in AY trials, because there is no misleading expectation to cause response interference, and costs in BX trials, in which a predominant response tendency triggered by the X probe has to be overcome. Two studies (Chiew & Braver, 2013; Locke & Braver, 2008) combined the AX-CPT with a reward manipulation: Both started with a baseline condition without monetary incentives followed by a performance-contingent reward block. Rewards were given for each correct reaction time (RT) faster than the individual median RT in the baseline block (Locke & Braver, 2008) or specifically in trials with an incentive precue and correct RTs within the fastest 30th percentile of individual baseline RTs (Chiew & Braver, 2013). The results showed a clear motivational effect of reward with generally faster RTs in the reward blocks. More importantly, the introduction of monetary incentives lead to the adoption of a proactive control strategy with increased error rates specifically on AY trials and RT benefits especially in B-cue trials. Another two studies (Dreisbach, 2006; van Wouwe et al., 2011) investigated purely affective influences on performance in the AX-CPT: Affect was manipulated with affective pictures—positive, neutral, or negative—from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) preceding every trial (Dreisbach, 2006) or with emotional film clips—positive or neutral—prior to the experiment (van Wouwe et al., 2011). As compared to neutral (and negative) affect, positive affect reduced error rates on AY trials (both studies), and resulted in costs specifically in B-cue trials in the Dreisbach study. Dreisbach interpreted this behavioral trade-off as evidence for reduced maintenance of the cue under positive affect, that is, reduced proactive control. Supported by additional analyses of event-related potentials—no change in cue-related potentials, affective modulation of probe-related potentials in AY trials—van Wouwe et al. came to the conclusion that positive affect increased reactive control. To sum up, reward manipulations increased proactive control, whereas positive affect reduced proactive and increased reactive control in the

AX-CPT. Taken together, these studies thus demonstrate—at odds with assumptions of the neuropsychological theory of positive affect (Ashby et al., 1999; Ashby et al., 2002)—diverging effects of reward and positive affect on cognitive control, suggesting that the source of positive affect is indeed a relevant factor.

Further studies (Braem et al., 2012; van Steenbergen et al., 2009, 2010, 2012), all using an Eriksen flanker paradigm (Eriksen & Eriksen, 1974), have indicated an even more complex picture by revealing diverging effects of performance-contingent and performance-noncontingent rewards. In these studies, performance-contingent reward (i.e., reward only for fast and correct responses) enhanced sequential adaptation effects (Braem et al., 2012; see also Stürmer et al., 2011), whereas performance-noncontingent reward (i.e., reward following a random subset of trials) or positive affect reduced sequential conflict adaptation (van Steenbergen et al., 2009, 2010, 2012). Though these studies used different reward and affect manipulations than the AX-CPT studies reviewed above, they again demonstrate oppositional effects of performance-contingent reward and positive affect. In addition, they suggest that giving random, performance-noncontingent rewards might have an effect similar to that of direct positive-affect induction. Taken together, the findings reviewed so far suggest that at least performance-contingent reward and positive affect are not interchangeable, since they do not allow the deduction of effects from one another. Thus, the origin of positive affect—via direct induction or as a consequence of performance-contingent or -noncontingent reward—seems to be an important but so far understudied issue. Consequently, recent reviews on the roles of reward and affect in cognitive control (Chiew & Braver, 2011; Dreisbach & Fischer, 2012) have stressed the importance of a clear differentiation between motivational and affective manipulations, called for further research to disentangle effects of reward and affect, and requested new integrative studies, which could combine these so far largely independent lines of research.¹

The present study was designed to directly compare the effects of reward and affect manipulations on cognitive control in a single experiment. For this purpose, we used a modified version of the AX-CPT, because of its proven sensitivity to reward and positive affect manipulations that we reviewed above (Chiew & Braver, 2013; Dreisbach, 2006; Locke & Braver, 2008; van Wouwe et al., 2011). The experiment started with a first phase, which included only an affect manipulation between participants (positive vs. neutral affect) via affective pictures comparable to those in the study by Dreisbach. In the second phase, the affect groups were split in half and received either performance-contingent or

-noncontingent rewards, resulting in a complete orthogonal design with the following groups: NeutralReward—that is, neutral affect plus performance-contingent reward; PositiveReward—that is, positive affect plus performance-contingent reward; NeutralRandomReward—that is, neutral affect plus performance-noncontingent reward; and PositiveRandomReward—that is, positive affect plus performance-noncontingent reward. The performance-contingent reward manipulation was similar to the procedure by Chiew and Braver (2013), with the first experimental phase serving as a baseline condition. With this integrative design, we would be able to directly investigate the possible interactions between positive affect and reward manipulations. Since, as was outlined above, both seem to have diverging effects on cognitive control (i.e., motivational as opposed to emotional), it is of major interest how the two might interact. In principle, both effects could coexist, or one effect could predominate over the other (see the more detailed hypotheses below). In any case, the results would be of theoretical and practical interest, since they might explain the somewhat heterogeneous literature on cognition–emotion interactions.

On the basis of previous results (Dreisbach, 2006; Fröber & Dreisbach, 2012; van Wouwe et al., 2011), the first phase was expected to replicate *positive affect* effects, in terms of reduced proactive control and/or increased reactive control, indicated by a benefit in AY trials and probable costs in B-cue trials. Again, following previous results (Chiew & Braver, 2013; Jimura et al., 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011), *performance-contingent reward* was expected to result in performance optimization via proactive control, indicated by increased error rates specifically on AY trials, and possibly faster responses in B-cue trials. This effect should be stronger on incentive than on nonincentive trials (cf. Chiew & Braver, 2013). On the basis of the results of van Steenbergen and colleagues (2009, 2010, 2012), we assumed that the effects of *performance-noncontingent reward* might resemble those of the positive affect manipulation. Therefore, no shift in cognitive control strategy was expected for participants in the PositiveRandomReward group in the reward phase. Performance in the NeutralRandomReward group would show whether the positive affect induced by random reward would overrule the neutral affect induced by neutral pictures. Of major interest would be the performance in the PositiveReward group, since it would be indicative of *how a motivational manipulation*, which typically results in an increase of proactive control, *interacts with a positive affect manipulation*, which typically results in a decrease of proactive control. Three different outcomes were feasible: (1) Both effects might coexist, resulting in a shift toward proactive control by adding performance-contingent rewards, but to a lesser extent than in the NeutralReward group; (2) the motivational effect might outweigh the positive affect effect, resulting in a preference for proactive control comparable to

¹ Another approach to shed further light on this complex interplay of reward and affective modulations of cognitive control can be found in a recent study by Braem et al. (2013).

that in the NeutralReward group; or (3) the already-established positive affect effect might resist a motivational manipulation, indicated by no change in cognitive control strategy from baseline to the reward phase.

Method

Participants

A group of 86 undergraduate students of Regensburg University participated in the experiment for course credit or €4. Without prior notice, participants received additional money—up to €8, dependent upon the reward condition—after the experiment. In all, 80 participants (see the Results for the exclusion criteria) were included in the final data analysis (mean age = 23.6 years, $SD = 4.04$, range 18–43; 66 female, 14 male). The participants were assigned randomly to the four experimental groups (20 NeutralReward, 20 PositiveReward, 20 NeutralRandomReward, and 20 PositiveRandomReward; no significant age differences between groups, $F < 1$). All participants signed informed consent and were debriefed after the session.

Apparatus

The experiment was run on a computer with a 17-in. monitor (display resolution at $1,024 \times 768$ pixels) at a viewing distance of approximately 50 cm. E-Prime 2.0 (Psychology Software Tools, Sharpsburg, PA, USA) was used for experiment presentation, and responses were collected via a QWERTZ keyboard, with the “y” and “m” keys serving as the left and right response keys.

Materials and procedure

Each trial of the AX-CPT consisted of a sequence of letters presented centered on a gray background. Only the cue–probe sequence “A followed by X” (AX trials) required a target response, whereas all other combinations (AY, BX, BY with B representing any non-A cue and Y representing any non-X probe) required a nontarget response. AX target trials occurred with a frequency of 70% and nontarget trials with a frequency of 10% each. A modified version of the AX-CPT was used with distractor letters appearing within the interval between cue and probe (cf. Dreisbach, 2006, Exp. 2). The actual letters A and X were used in AX trials. B-cues, Y-probes, and distractor letters were chosen randomly from the remaining letters of the alphabet, direct repetitions were not allowed. To facilitate the discrimination between cue, probe, and distractor letters, distractors were presented in black (Arial font, bold, size 24) whereas cue and probe were presented in magenta (Arial font, bold, size 28). Participants were informed that only the colored letters were relevant for the task.

Affective pictures from the IAPS (Lang et al., 1999) were used as affect induction procedure (cf. Dreisbach, 2006). These pictures have been shown to reliably elicit specific affective reactions, even with shorter presentation durations than in the present experiment (Codispoti, Mazzetti, & Bradley, 2009). Ten neutral and ten positive pictures with low arousal were selected, which have already been used in a previous study (Fröber & Dreisbach, 2012; see the Appendix Table 2 for the numbers of the specific IAPS pictures). The mean ratings from IAPS norms for the neutral picture set were valence = 4.99 and arousal = 2.45, and for the positive picture set valence = 7.99 and arousal = 4.55. All pictures were presented in landscape format, adjusted to a size of 800×600 pixel, and positioned centered on a grey background. Pictures were displayed in random order with the exclusion of direct repetitions. Participants were told that those pictures, like the distractor letters, were irrelevant for the task.

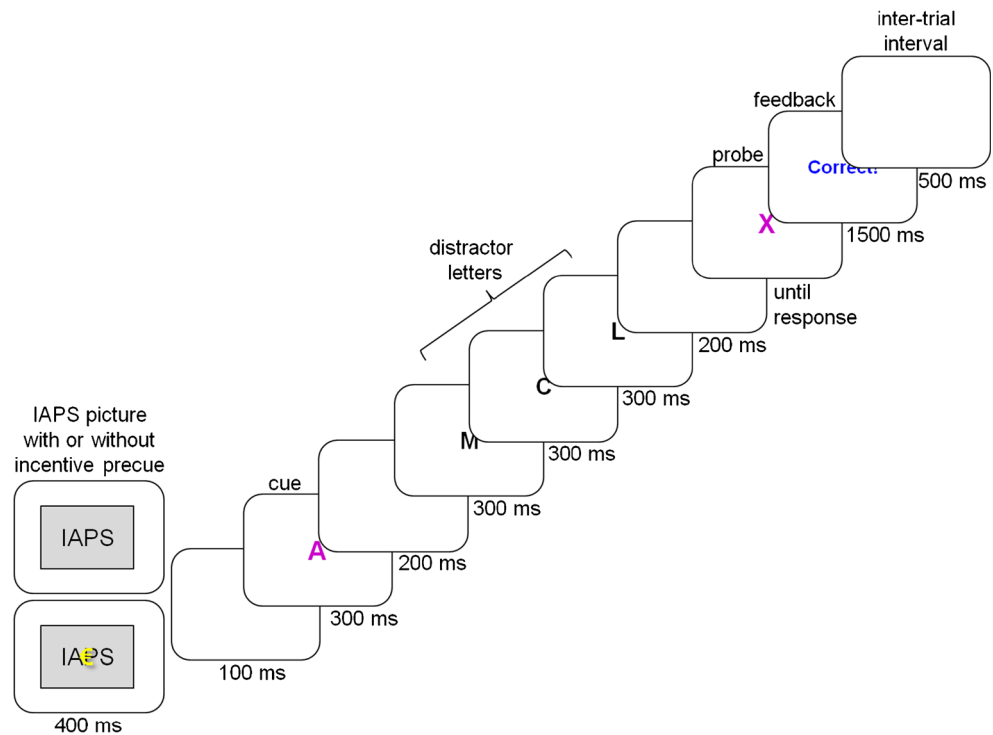
Each trial started with the presentation of an IAPS picture—neutral or positive, according to group—for 400 ms, followed by a short blank screen (100 ms). The cue appeared for 300 ms, followed by another blank screen (200 ms), a consecutive presentation of the three distractor letters (300 ms each), and another blank screen (200 ms). After that, the probe appeared and remained on screen until the participant responded. The response mapping of the target and nontarget responses to the left or the right response key was counterbalanced across participants. Responses were followed by an informative feedback for 1,500 ms, which presented the word *Richtig!* (German for “correct”) in blue after correct responses, or *Falsch!* (German for “wrong”) in red after errors. The next trial started after an intertrial interval of 500 ms (see Fig. 1).

The whole experiment consisted of two baseline blocks of 80 trials each (56 AX, 8 AY, 8 BX, and 8 BY, randomly intermixed), with only the affect induction—neutral or positive IAPS pictures preceding every trial (cf. Dreisbach, 2006)—included, followed by another two blocks of 160 trials each (112 AX, 16 AY, 16 BX, and 16 BY, randomly intermixed), with the addition of two different reward manipulations—performance-contingent or -noncontingent (see Fig. 2).

In both reward conditions, half of the trials started with an incentive precue, which was a yellow Euro symbol (€, in 48-point bold Arial font) presented centrally and superimposed on the IAPS picture (see Fig. 1). For the performance-contingent reward manipulation (cf. Chiew & Braver, 2013), participants were informed that they could win additional money (5 cents per incentive trial) on precued trials if their response was accurate and fast enough. The individual RT thresholds for reward receipt were derived from the baseline performance²: For each trial type (AX, AY, BX, and BY), RTs

² Individual RT thresholds were determined in the second baseline block as a precautionary measure, to prevent possible practice effects. Analyses of the block effects can be found online (in the supplementary materials).

Fig. 1 Trial structure of an example AX trial (target trial), with an IAPS picture presented with or without an incentive precue (yellow Euro sign) shown. In the second experimental (reward) phase, the Euro sign was superimposed on the IAPS picture on half of the trials to indicate that a monetary reward could be achieved on the following trial. In each trial, only the two colored letters (cue and probe) were relevant for the task

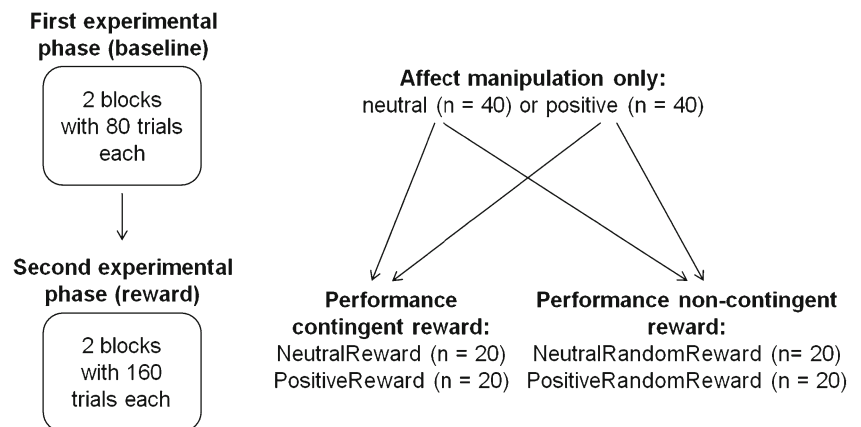


had to be within the fastest third of correct RTs for an individual’s baseline performance. In the incentive trials, the feedback messages were changed to *Richtig! Bonus erhalten* (“Correct! Bonus won”) in green for correct answers within the RT criterion, *Zu langsam! Kein Bonus* (“Too slow! No bonus”) in blue for correct answers that were slower than the RT criterion, and *Falsch! Kein Bonus* (“Wrong! No bonus”) in red for errors. For the performance-noncontingent reward manipulation, participants were informed that they would receive extra money as a gift (5 cents per incentive trial) whenever the incentive precue appeared at the beginning of a trial. For these trials, the feedback messages were changed to *Richtig! Bonus erhalten* (“Correct! Bonus won”) in green for

correct answers, and *Falsch! Bonus erhalten* (“Wrong! Bonus won”) in red for errors (see Fig. 3). Thus, the difference between the two reward conditions was that in the random-reward groups, any response in incentive trials (correct or incorrect, irrespective of RT) was rewarded with 5 cents, whereas in the performance-contingent reward groups, only the respective correct and fast reactions (below the individual threshold) were rewarded.

Participants were asked to answer as quickly and accurately as possible. The experiment started with written instructions and ten practice trials (seven AX, one AY, one BX, and one BY, randomly intermixed) to explain the task. The instructions included no prior notice regarding the upcoming reward

Fig. 2 Overview of the structure of the experiment. The experiment started with two between-subjects affect groups (neutral and positive), which were subdivided into four orthogonal groups (NeutralReward, PositiveReward, NeutralRandomReward, and PositiveRandomReward) by the introduction of two different reward conditions in the second phase of the experiment



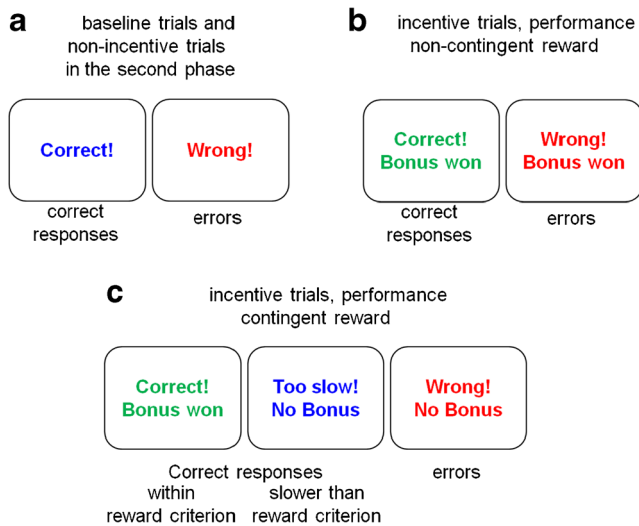


Fig. 3 Overview of informative feedback conditions, showing English translations of the original German feedback. **(a)** Feedback for all trials of the first experimental phase (baseline) and for nonincentive trials of the second (reward) phase in all experimental groups. **(b)** Feedback for incentive trials of the second phase in the performance-noncontingent reward conditions (NeutralRandomReward and PositiveRandomReward groups). **(c)** Feedback for incentive trials of the second phase in the performance-contingent reward conditions (NeutralReward and PositiveReward groups). The feedback message “Bonus won” meant an addition of 5 cents to the participant’s payment

manipulations in the second phase. A feedback message after the first reward block informed participants about their reward sum so far (individual scores for performance-contingent reward, or €4 for a performance-noncontingent reward), and the total reward sum (individual scores or €8) was reported at the end of the experiment. The four experimental blocks were separated by self-paced breaks. After the experiment, all participants filled out the Behavioral Inhibition System/Behavioral Activation System scales (BIS/BAS; Carver & White, 1994) in a translated version (Strobel, Beauducel, Debener, & Brocke, 2001). Of particular interest for this study was the BAS Reward Responsiveness subscale, to explore associations with reward-related individual differences.

Design

In the first phase of the experiment, the baseline phase, a 2 (affect: neutral, positive) \times 4 (cue–probe condition: AX, AY, BX, BY) design was used. Affect was a between-participants variable, and cue–probe condition was manipulated within participants. In the second experimental phase, the reward phase, the design was extended to a 2 (affect) \times 2 (contingency: contingent, random) \times 4 (cue–probe condition) \times 2 (incentive: incentive, nonincentive) design with the additional between-participants variable contingency and the within-participants factor Incentive. Reaction times (in milliseconds) and error rates (as percentages) served as the dependent measures.

Results

Data analysis

Practice trials as well as the first trial of each experimental block were excluded from the analysis. In addition, error trials were removed prior to the RT analyses (3.96% of the data). The data of five participants were excluded from further analysis, due to exceptionally slow RTs in the baseline phase as compared to the means of the respective affect groups ($M > 699$ ms vs. $M_{\text{neutral}} = 355$ ms, $SD_{\text{neutral}} = 78.03$; $M > 504$ ms vs. $M_{\text{positive}} = 333$ ms, $SD_{\text{positive}} = 62.64$), and one further participant was excluded because of too many errors in the baseline blocks ($M = 24.3\%$ vs. $M_{\text{positive}} = 2.7\%$, $SD_{\text{positive}} = 2.89$). Of the remaining data, the mean error rates and mean median RTs for each cue–probe condition were collapsed over blocks³ (the additional analysis including the factor Block (1, 2) in the respective baseline or reward phases can be found online in the [supplementary materials](#)) and entered into two 2 (affect) \times 4 (cue–probe condition) mixed-factors analyses of variance (ANOVAs) for the baseline phase. The reward phase was analyzed with 2 (affect) \times 2 (contingency) \times 4 (cue–probe condition) \times 2 (incentive) mixed factors ANOVAs. In order to look into the global reward effects, we also analyzed the transition from baseline to reward phase for each experimental group separately with 2 (phase: baseline, reward) \times 4 (cue–probe condition) repeated measures ANOVAs, separately for the mean error rates and mean median RTs. Note that only nonincentive trials of the reward phase were included, because the procedure therein was identical to the procedure in baseline trials (cf. Chiew & Braver, 2013). Furthermore, to minimize the impact of practice effects, only data from the second baseline block and first reward phase block were entered into the analyses.

Baseline

The baseline phase included an affect manipulation (neutral vs. positive) only. Thus, the results from baseline analyses would be comparable to those of previous studies investigating AX-CPT performance under positive affect (Dreisbach, 2006; van Wouwe et al., 2011).

Error data The left panel of Fig. 4 shows mean error rates as a function of affect (neutral, positive) and cue–probe condition (AX, AY, BX, BY). The 2 \times 4 ANOVA revealed significant main effects of affect, $F(1, 78) = 7.87$, $p < .01$, $\eta^2_p = .091$, and cue–probe condition, $F(3, 234) = 43.08$, $p < .001$, $\eta^2_p = .355$,

³ Although blockwise analyses showed some indications of practice effects, the main findings for positive affect and reward contingency effects were not reliably affected. Thus, for the sake of parsimony, only analyses without the factor Block are reported in the main text.

and a significant Affect \times Cue–Probe Condition interaction, $F(3, 234) = 5.48, p < .01, \eta^2_p = .066$. In line with our predictions, planned comparisons showed a specific benefit in AY trials under positive affect as compared to neutral affect ($F = 6.67, p < .05, 7.4\%$ vs. 14.6%), whereas the error rates in all other cue–probe conditions (AX, BX, BY) did not differ significantly between groups (all F s < 3.13 , all p s $> .08$).

RT data The right panel of Fig. 4 shows mean RTs as a function of affect (neutral, positive) and cue–probe condition (AX, AY, BX, BY). The 2×4 ANOVA revealed a significant main effect of cue–probe condition, $F(3, 234) = 250.5, p < .001, \eta^2_p = .763$, as well as a significant Affect \times Cue–Probe Condition interaction, $F(3, 234) = 2.84, p < .05, \eta^2_p = .035$. Single comparisons showed significant differences between all cue–probe conditions (all F s > 15 , all p s $< .001$). The two-way interaction mirrored the error pattern by again revealing a specific AY benefit under positive affect. Planned comparisons showed significantly faster RTs in the positive than in the neutral group in AY trials ($F = 5.78, p < .05, 469$ vs. 524 ms), whereas no significant differences were found in all other cue–probe conditions (all F s < 1.26 , all p s $> .265$). The main effect of affect did not prove reliable ($F = 1.98, p = .164$).

Reward phase

Transient effects of the reward manipulations were analyzed by comparing incentive and nonincentive trials within the reward phase (cf. Chiew & Braver, 2013). Furthermore, our integrative design allowed for direct comparisons between reward contingency manipulations (contingent, random), affective manipulations (neutral, positive), and interactions of both manipulations.

Error data Figure 5 shows mean error rates as a function of affect (neutral, positive), contingency (contingent, random), cue–probe condition (AX, AY, BX, BY), and incentive (incentive, nonincentive). The $2 \times 2 \times 4 \times 2$ ANOVA revealed significant main effects of contingency, $F(1, 76) = 58.91, p < .001, \eta^2_p = .437$, and cue–probe condition, $F(3, 228) = 156.65, p < .001, \eta^2_p = .673$, which were further qualified by a significant Contingency \times Cue–Probe Condition interaction, $F(3, 228) = 60.36, p < .001, \eta^2_p = .443$. The main effect of incentive, $F(1, 76) = 3.78, p = .056, \eta^2_p = .047$, almost reached significance, whereas the main effect of affect ($F < 1, p = .566$) and all other interactions (all F s < 1.85 , all p s $> .178$) did not prove reliable. Planned comparisons on the significant two-way interaction showed that participants in the performance-contingent reward groups (NeutralReward, PositiveReward) made significantly more errors on AY and AX trials than did participants in the performance-noncontingent reward groups (NeutralRandomReward, PositiveRandomReward); $F = 63.2, p < .001, 47\%$ vs. 12% , and $F = 4.1, p < .05, 1.76\%$ vs. 0.8% ,

respectively. No significant differences were found in B-cue trials (all F s < 2.12 , all p s $> .149$). So, irrespective of the actual availability of a reward on a given trial (i.e., in nonincentive as well as incentive trials), performance-contingent reward led to more errors, especially in A-cue trials—and the effect was more pronounced in AY than in AX trials—consistent with a proactive control bias.

RT data Figure 6 shows mean RTs as a function of affect (neutral, positive), contingency (contingent, random), cue–probe condition (AX, AY, BX, BY), and incentive (incentive, nonincentive). The $2 \times 2 \times 4 \times 2$ ANOVA⁴ revealed significant main effects of contingency, $F(1, 75) = 34.68, p < .001, \eta^2_p = .316$, cue–probe condition, $F(3, 225) = 575.2, p < .001, \eta^2_p = .885$, and incentive, $F(1, 75) = 21.18, p < .001, \eta^2_p = .22$, as well as a significant Contingency \times Incentive interaction. The main effect of affect ($F = 2.74, p = .102$) and all other interactions did not prove reliable (all F s < 1.54 , all p s $> .205$). Planned comparisons showed significant differences between all cue–probe conditions (all F s > 239 , all p s $< .001$), except for the two B-cue sequences ($F < 1, p = .856$). Participants in the performance-contingent reward groups (NeutralReward and PositiveReward) were generally faster than participants in the non-performance-contingent reward groups (NeutralRandomReward and PositiveRandomReward, 250 vs. 317 ms). In addition, the significant two-way Reward \times Incentive interaction revealed faster RTs in incentive than in nonincentive trials (25 ms) for the performance-contingent reward groups only ($F = 22.7, p < .001$), whereas this incentive effect did not prove reliable in the performance-noncontingent reward groups ($F = 2.97, p = .089$).

Transitions from baseline to reward phase

Sustained effects of the reward manipulation were analyzed by directly comparing the baseline with reward-phase performance (nonincentive trials only; cf. Chiew & Braver, 2013). Our study included four different kinds of transitions from baseline to the reward phase (NeutralReward, PositiveReward, NeutralRandomReward, PositiveRandomReward). Therefore, four separate 2 (phase: baseline, reward) \times 4 (cue–probe condition: AX, AY, BX, BY) mixed-factors ANOVAs on error rates and mean median RTs were conducted, to see how the introduction of rewards (performance-contingent or noncontingent) would influence the affective modulation of AX-CPT performance. Analyses for all four experimental groups included only the second baseline and first reward block, to minimize the influence of practice effects.

⁴ In the reward phase, total sample size was reduced to $N = 79$ in the RT analysis, because the mean RTs from one participant in the NeutralReward group were incomplete, due to 100% errors specifically in AY trials.

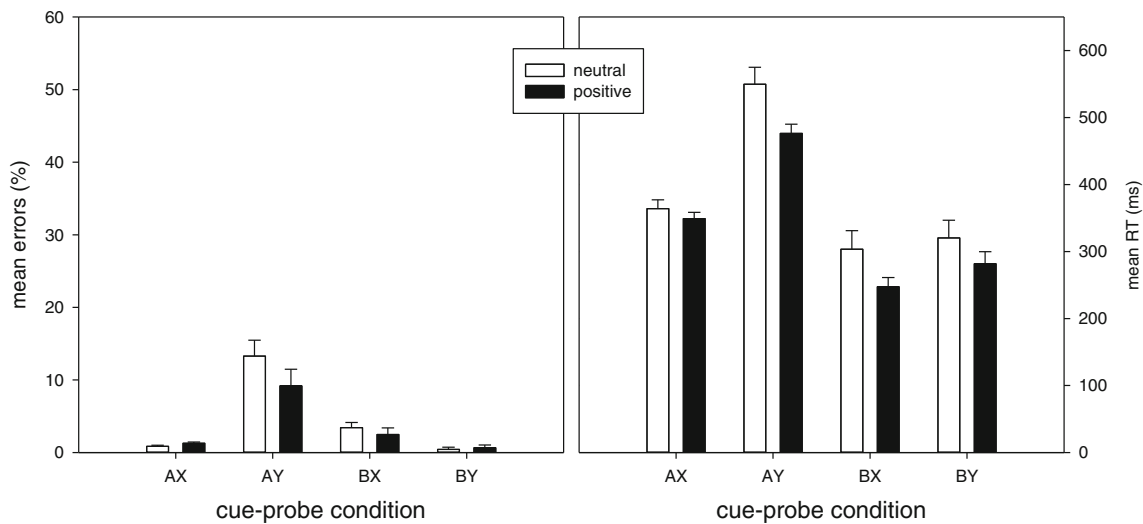


Fig. 4 Mean error rates in percentages (left panel) and mean reaction times (RTs) in milliseconds (right panel) in the first experimental phase, as a function of affect and cue-probe condition. Error bars represent one standard error of the mean

NeutralReward group The error rate analysis revealed significant main effects of phase, $F(1, 19) = 38.56, p < .001, \eta^2_p = .670$, and cue-probe condition, $F(3, 57) = 63.13, p < .001, \eta^2_p = .769$, which were further qualified by a significant two-way interaction, $F(3, 57) = 38.86, p < .001, \eta^2_p = .672$. Planned comparisons showed an increase in error rates from the baseline to the reward phase in AY trials only (14.02% vs. 47.05%; $F = 40.83, p < .001$; all other cue-probe sequences: $F < 1, p > .543$). The same analysis with mean median RTs resulted in significant main effects of phase, $F(1, 19) = 29.68, p < .001, \eta^2_p = .61$, with generally faster RTs in the reward phase (271 vs. 334 ms), and a significant main effect of cue-probe sequence, $F(3, 57) = 190.6, p < .001, \eta^2_p = .909$. Planned comparisons showed significant differences between all cue-probe sequences (all $F_s > 37.73, p_s < .001$; BX vs. BY on the threshold of

significance: $F = 4.28, p = .052$). The two-way interaction did not prove reliable ($F < 1, p = .597$).

PositiveReward group The error rate analysis mirrored the results of the NeutralReward group, with significant main effects of phase, $F(1, 19) = 39.39, p < .001, \eta^2_p = .675$, and cue-probe sequence, $F(3, 57) = 25.44, p < .001, \eta^2_p = .572$, as well as a significant two-way interaction, $F(3, 57) = 33.18, p < .001, \eta^2_p = .636$. Again, specifically AY errors increased from the baseline to the reward phase (5.0% vs. 36.25%, $F = 37.7, p < .001$; all other cue-probe sequences: $F < 2.82, p > .109$). The RT analysis also showed significant main effects of phase, $F(1, 19) = 33.26, p < .001, \eta^2_p = .636$, and cue-probe sequence, $F(3, 57) = 190.84, p < .001, \eta^2_p = .909$, as well as a significant two-way interaction, $F(3, 57) = 6.45,$

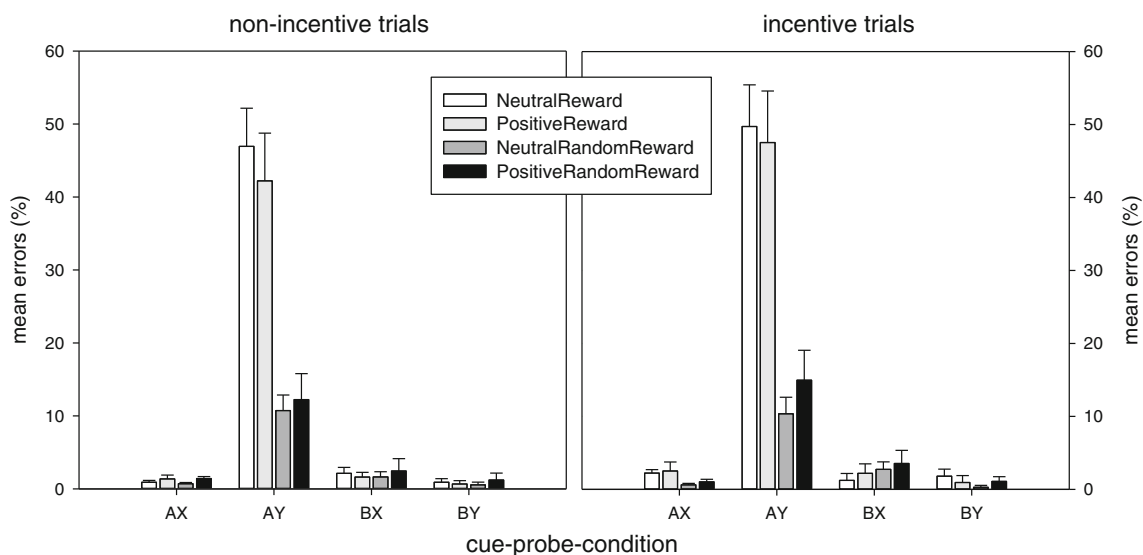


Fig. 5 Mean error rates (in percentages) of the reward phase as a function of affect, contingency, cue-probe condition, and incentive. Error bars represent one standard error of the mean

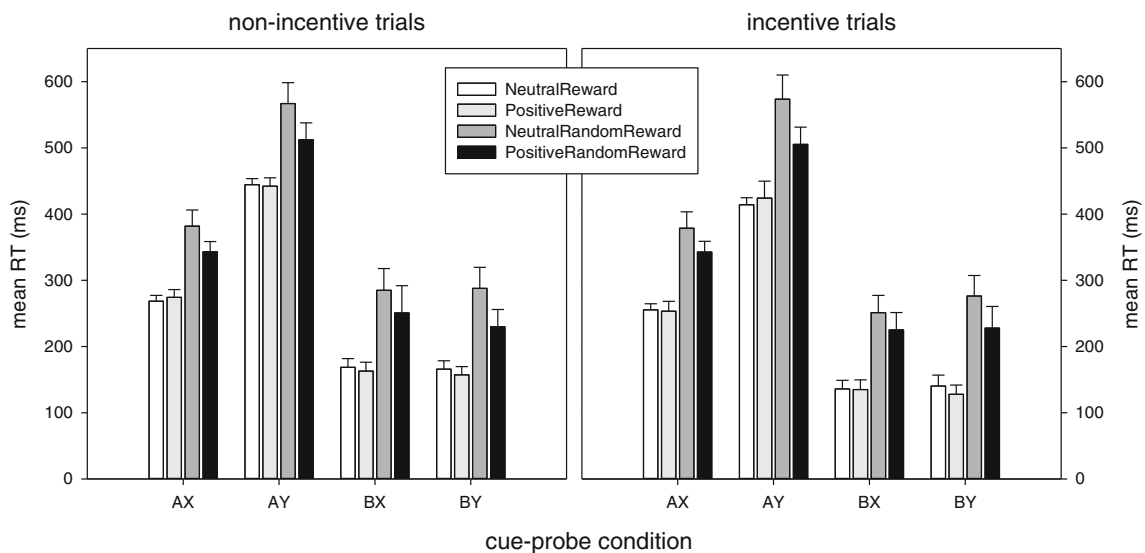


Fig. 6 Mean reaction times (RTs, in milliseconds) of the reward phase as a function of affect, contingency, cue-probe condition, and incentive. Error bars represent one standard error of the mean

$p < .001$, $\eta^2_p = .254$. Planned comparisons revealed faster RTs from the baseline to the reward phase in all cue-probe sequences (all F s > 10.57 , $ps < .01$), except for AY trials ($F = 3.15$, $p = .092$).

NeutralRandomReward group The error rate analysis showed significant main effects of phase, $F(1, 19) = 13.0$, $p < .01$, $\eta^2_p = .406$, and cue-probe sequence, $F(3, 57) = 14.54$, $p < .001$, $\eta^2_p = .432$, which were further qualified by a significant two-way interaction, $F(3, 57) = 4.98$, $p < .01$, $\eta^2_p = .208$. In contrast to both performance-contingent reward groups, planned comparisons on the two-way interaction revealed *decreased* error rates from baseline to the reward phase specifically in AY trials (16.43% vs. 7.59%; $F = 8.17$, $p < .05$) and a marginally significant decrease in BX trials (3.75% vs. 0.63%; $F = 4.13$, $p = .056$; AX and BY trials: $F < 2.37$, $p > .14$). The RT analysis resulted in a significant main effect of cue-probe sequence, $F(3, 57) = 60.75$, $p < .001$, $\eta^2_p = .762$, with significant differences between all cue-probe sequences (all F s > 22.36 , $ps < .001$), except for BX and BY ($F = 1.0$, $p = .333$). The main effect of phase ($F < 1$, $p = .937$) and the two-way interaction ($F = 1.02$, $p = .392$) did not prove reliable.

PositiveRandomReward group The error rate analysis showed only a significant main effect of cue-probe sequence, $F(3, 57) = 10.22$, $p < .001$, $\eta^2_p = .35$. Planned comparisons showed no significant difference between AX and BX trials ($F < 1$, $p = .794$) and BX and BY trials ($F = 1.88$, $p = .186$), whereas all other comparisons were significant (all F s > 8.37 , $ps < .01$). The main effect of phase ($F = 1.11$, $p = .163$) and the two-way interaction ($F < 1$, $p = .704$) did not prove reliable. The RT analysis likewise revealed only a significant main

effect of cue-probe sequence, $F(3, 57) = 116.66$, $p < .001$, $\eta^2_p = .860$, but no significant main effect of phase ($F < 1$, $p = .93$) nor a significant two-way interaction ($F < 1$, $p = .58$). Planned comparisons showed significant differences between all cue-probe sequences (all F s > 25.14 , $ps < .001$), except for BX and BY trials ($F = 1.55$, $p = .229$).

In sum, these analyses show that the introduction of performance-contingent reward in both affect groups led to a general speedup in RTs and increased error rates specifically in AY trials, consistent with a shift toward a more proactive control strategy. In contrast, random, performance-noncontingent reward had no effect on RTs. In the NeutralRandomReward group, AY error rates decreased in the reward context—indicating a shift toward less proactive/more reactive control—whereas error rates were not affected by the reward manipulation in the PositiveRandomReward group—indicating no change in their cognitive control strategy.

Reward responsiveness, total reward sum, and BAS scores

The participants in both performance-contingent reward groups, NeutralReward and PositiveReward, achieved above-criterion performance—that is, they actually received rewards—on 71.25% of the incentive trials, versus the expected rate of 33% reward from baseline performance (see also Chiew & Braver, 2013, who found 78.5% reward reception with a comparable performance criterion). That is, on average, participants earned €5.7 of additional money (range €2.2–€7.45), whereas the total reward sum did not differ significantly between both groups ($t < 1$, $p = .65$; see Table 1 for descriptive statistics). Ratings on the BAS Reward Responsiveness subscale also did not differ significantly in

the four experimental groups ($F < 1, p = .963, M = 3.31, SD = 0.35$; see Table 1 for the group means and standard deviations). To see whether reward responsiveness was associated with the range of received rewards (in both performance-contingent reward groups), individual BAS scores on the respective subscales were correlated with the individual total reward sum. A significant positive correlation⁵ was found between total reward sum and BAS Reward Responsiveness rating in the PositiveReward group only, $r = .494, p < .05$, indicating that the variability in the amount of reward received might be explained by individual reward sensitivity, to some extent. No such relationship was found for the NeutralReward group ($r = .094, p = .347$).

General discussion

Purpose of the present study was to investigate whether positive affect from different sources—direct affect induction, performance-contingent or -noncontingent reward—has different influences on cognitive control processes. To this end, we used an integrative design to directly compare effects of reward and positive affect manipulations in a modified AX-CPT within a single study. In short, the present results replicated the typical affect effect in terms of specific benefits in AY trials under positive affect as compared to neutral affect (Dreisbach, 2006; van Wouwe et al., 2011). Also, typical reward effects, in the form of accelerated RTs and error costs in AY trials, could be replicated in the NeutralReward condition (Chiew & Braver, 2013; Locke & Braver, 2008). Interestingly, the same reward effect was also found in the PositiveReward but not in the performance-noncontingent reward conditions (NeutralRandomReward and PositiveRandomReward).⁶ That is, the introduction of performance-contingent reward caused an elimination of the AY benefit usually found under positive affect, and instead impaired performance in AY trials comparably to what was seen in the NeutralReward group. In contrast, adding random reward to the positive group had no further modulatory influence on behavior; that is, the positive affect effect, in terms of an AY benefit, remained stable throughout the experiment in the PositiveRandomReward group. Moreover, adding random reward to the neutral group was accompanied by reduced AY errors in the reward phase, resulting in similar performance in both performance-noncontingent reward groups. Finally, reward sensitivity, as measured by the BAS Reward Responsiveness subscale, did

not differ between groups, but did significantly correlate with the total amount of reward received in the PositiveReward but not in the NeutralReward group.

Behavioral consequences of affect versus reward contingency

With respect to the DMC framework (Braver, 2012; Braver et al. 2007), behavior particularly in AY and BX trials can be used to index changes in cognitive control strategies. In the present study, performance in AY trials proved to be most sensitive to the experimental manipulations. In the AX-CPT paradigm, an AY trial is the only cue–probe sequence, in which a proactive control strategy actually worsens performance: utilizing actively maintained context information—in this case, the cue letter A—results in a strong tendency for a target response (due to the high frequency of AX target trials), which has to be overcome when the unexpected probe Y appears. Consequently, any manipulation that affects proactive control should affect performance on AY trials as will be discussed below. We found no specific influences of affect or reward contingency on BX trial performance. Differences from previous studies will be addressed below.

Positive affect

The specific benefit in AY trials under positive affect—less errors and faster RTs in the baseline phase—as compared to neutral affect can be interpreted as an indicator for less proactive control and more reactive control (see also Fröber & Dreisbach, 2012). This response pattern perfectly fits with results from a previous study (van Wouwe et al., 2011), which moreover could show that positive affect influences event-related potentials associated with reactive control processes. Another previous study (Dreisbach, 2006) found that this AY benefit under positive affect was accompanied by costs in B-cue trials, indicating that positive affect is beneficial when a to be maintained goal unexpectedly changes (i.e., in AY trials), but detrimental when it has to be executed (i.e., in BX and BY trials). The absence of behavioral costs under positive affect in the present study might be a consequence of differing feedback procedures.⁷ The present study included an informative feedback following each trial, whereas in the Dreisbach study feedback was only given to errors. Since action effects have a motivational impact (Eitam, Kennedy, & Higgins, 2013), the differential feedback might have resulted in motivational

⁵ Excluding one outlier with an (especially low) total reward sum of €2.2 reduced this correlation to a marginally significant effect ($r = .36, p = .065$).

⁶ Note that in comparison with the performance-noncontingent reward groups, we found evidence for sustained as well as transient reward effects, in terms of faster RTs on incentive than on nonincentive trials in the contingent-reward groups (see also Chiew & Braver, 2013).

⁷ The Dreisbach (2006) study and the AX-CPT study from van Wouwe et al. (2011) differed in more aspects than feedback procedure. For example, in the latter study an affect induction procedure with emotional film clips prior to the actual experiment was used. Also, the AX-CPT procedure was different than in the earlier study, with additional no-go trials included, but without distractor letters between the cue and probe, and without any feedback. Therefore, it is not clear how the control feedback hypothesis is applicable to these behavioral differences.

Table 1 Means, standard deviations, and range of total reward sum and BAS reward responsiveness ratings for all four experimental groups

	Total Reward Sum			BAS Reward Responsiveness Ratings		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
NeutralReward	€5.8	0.79	€4.55–€7.45	3.28	0.28	2.8–3.8
PositiveReward	€5.6	1.15	€2.20–€7.25	3.34	0.35	2.8–4.0
NeutralRandomReward	€8 fixed			3.35	0.43	2.6–4.0
PositiveRandomReward	€8 fixed			3.3	0.39	2.6–3.8

differences, so that participants in the Dreisbach study showed an increased impact of positive affect on cognitive control with even less proactive control (see the supplementary materials, Table S11, for a direct comparison of the effect sizes in the present study and in the Dreisbach, 2006, study). Note that, in everyday life, this reluctant usage of proactive control might serve an adaptive function. According to the DMC framework (Braver, 2012; Braver et al., 2007), proactive control is associated with more effort than reactive control, because it involves sustained maintenance of informative context cues or task goals to optimize behavior via preparation. With respect to functional theories on positive affect (e.g., Carver, 2003; Schwarz, 1990, 2012), positive affect (and random reward) could have served as a feedback or safety signal indicating the opportunity to refrain from proactive control in terms of sustained task preparation—thereby conserving effort—and instead rely on reactive control as soon as the target appears.

Random, performance-noncontingent reward

In line with a series of studies by van Steenbergen and colleagues (2009, 2010, 2012), our study showed similar behavior under positive affect and performance-noncontingent reward. More precisely, the performance difference between neutral and positive affect in the baseline was no longer present in the reward phase: Introducing performance-noncontingent reward did not affect performance in the PositiveRandomReward group, suggesting no change in cognitive control strategies. In the NeutralRandomReward group, however, the transition from the baseline to the reward phase was accompanied by decreased error rates specifically in AY trials, indicating a shift toward reduced proactive control and/or increased reactive control.

At this point, it is important to note that our performance-noncontingent reward manipulation differed in two ways from the respective reward procedures in the van Steenbergen et al. (2009, 2012) studies. First, receipt of a reward in the van Steenbergen (2009, 2012) studies was always signaled by a smiley face, which makes it hard to decide whether participants experienced this cue rather as an affect or a reward cue. Second, participants in the van Steenbergen (2009, 2012) studies were not given any precues announcing a potential

reward but instead only learned about the reward via performance feedback whereas our participants were cued before a given reward trial. However, and interestingly so, within the literature so far, consistent differences have only been reported for reward contingency (contingent vs. not) but not for anticipation (with precue vs. without). That is, rewards are often announced with precues—thereby allowing anticipation of reward *before* task performance (cf. Chiew & Braver, 2013; Jimura et al., 2010; Kleinsorge & Rinkebaer, 2012; Locke & Braver, 2008; Padmala & Pessoa, 2011), whereas other studies give performance (non)contingent rewards as feedback only—that is, *after* task performance (Braem et al., 2012; Stürmer et al., 2011; van Steenbergen et al., 2009, 2012).⁸ However, so far only contingency but not anticipation provided consistent and diverging effects on cognitive control (Dreisbach & Fischer, 2012, and this study). This of course might be an interesting endeavor for future research.

On a more general level, it seems remarkable that our noncontingent reward manipulation—with anticipation of a certain reward irrespective of task performance (accuracy and RT level)—was not accompanied by more drastic changes of behavior. Note that participants were rewarded entirely independent from current behavior, even for error execution. Therefore, a complete disengagement from the task—for example, by pressing the same response key on every trial irrespective of the current cue–probe sequence—would have been a possible strategy without any negative consequences. Participants would still have gained the same amount of additional money, and even with less effort. Since effort minimization in terms of avoiding physical as well as cognitive demands is assumed to be a natural preference in human behavior (Hull, 1943; Kool, McGuire, Rosen, & Botvinick, 2010), the enduring task engagement in the random-reward groups calls for an explanation. First of all, the feedback procedure in the present experiment remained informative—that is, contingent on current task performance—which might have caused enough motivation to maintain task engagement

⁸ Note, however, that participants in those studies that did not precue the reward on a trial-by-trial basis were still informed that they would be rewarded on some portion of the trials (either depending or not depending on task performance). So, one might argue that reward anticipation is present in all studies, either sustained or transient (depending on the precue).

(cf. Eitam et al., 2013). Second, correct responses as compared to errors are associated with intrinsic reward signals, which can foster task engagement (i.e., intrinsic motivation) irrespective of extrinsic rewards or explicit feedback (Satterthwaite et al., 2012). Third, the positive affect as a consequence of the random reward might have kept participants in good temper to continue following the task instructions. And this, in sum, might have resulted in a reduced risk of performing errors in the first place such that, overall, only very few errors were actually rewarded. And finally, effort minimization might only apply to situations associated with higher task demands (Kool et al., 2010), whereas, with the rather simple AX task used here, maintaining task engagement might have been more attractive than task disengagement that would have been associated with repeated (and presumably aversive) error feedback. In any case, we believe the fact that rewarding errors does not result in sloppy performance is indeed remarkable and might be a promising topic for future research.

Performance-contingent reward

In both affect groups, performance-contingent reward resulted in generally accelerated RTs⁹ and a remarkably high error rate specifically in AY trials indicating that the prospect of receiving additional money caused participants to predominantly use a preparatory, proactive control strategy (see also Jimura et al., 2010; Padmala & Pessoa, 2011). This strategy was successful, as can be seen in the above-expected rate of actually received rewards (over 70% rewarded incentive trials vs. an expected 33%, based on baseline performance). In sum, these results are perfectly consistent with previous studies investigating influences of performance-contingent reward within the AX-CPT (Chiew & Braver, 2013; Locke & Braver, 2008). Interestingly, in all these studies specific reward effects were most pronounced for changes in AY error rates, suggesting that AY trial performance is a more sensitive indicator for changes toward proactive control than BX trial performance. Again in line with previous research, the motivational effect of reward—generally faster RTs combined with increased error rates specifically in AY trials—was found for incentive as well as (albeit to a lesser degree) nonincentive trials (Chiew & Braver, 2013; Jimura et al., 2010; Kleinsorge & Rinkeauer, 2012; Zedelius, Veling, Bijleveld, Aarts, & Daunizeau, 2012). It thus seems that the context of reward expectancy together with an established reward association to a given task suffices to induce a shift to a more proactive control mode resulting in a generally facilitative effect on

behavior. Note that this cannot be attributed to practice effects because the RandomReward conditions had just the same amount of practice and still did not shift to a more proactive control strategy. Like the effort conserving influence of positive affect, this effort increasing influence of performance-contingent reward seems to be a basic, adaptive mechanism (see the reviews by Bijleveld, Custers, & Aarts, 2012a, b).

It is noteworthy, that in all studies mentioned here reward achievement was contingent on both accuracy and RTs. However, given that the effects are most pronounced in terms of AY errors, one might argue that these reward effects are no motivational enhancement of task performance due to a shift of cognitive control strategy, but instead mere results of a speed–accuracy trade-off. What speaks against this assumption is that performance-contingent reward resulted in generally faster RTs, whereas error rates from baseline to reward phase increased in AY trials only (see also Chiew & Braver, 2013; Locke & Braver, 2008). Moreover, we can rule out that participants applied a pure speed strategy like for example always preparing for a target response after A-cues and always preparing for a non.-target response after a B-cue no matter what the target. With such a strategy participants should have gained 90% of the maximum reward at the expense of 100% errors on AY trials. Instead, the comparison of reward-phase performance showed that performance-contingent reward as compared to performance-noncontingent reward affected error rates in both A-cue trials—but more so on AY trials—suggesting a true shift toward proactive control. That is, error rates increased specifically in less predictive cue–probe conditions (A-cue trials).¹⁰

Interaction of positive affect and performance-contingent reward

The combination of affect and reward manipulations in a single experiment allows first conclusions on how these two opposing effects, the effort increasing motivational effect, on the one side, and the effort conserving affect effect, on the other side, interact. The results were clear cut: The motivational effect of performance-contingent reward in terms of increased proactive control counteracted and virtually eliminated the positive affect effect from the baseline condition. An open question at this point is, why motivational effects—induced by performance-contingent rewards—predominate positive affect effects. From an evolutionary perspective, adaptive reward pursuit—for instance, increasing effort to gain access to food, sexual partners or safety—has been essential for human survival, and should therefore have

⁹ In the PositiveReward group, analysis of the transition from the baseline to the reward phase showed a significant RT speedup in all cue–probe sequences, but only descriptively decreased RTs in AY trials. This non-significant decrease in AY trials might be a consequence of the preexisting positive affect effect found in the baseline, in terms of faster RTs specifically in AY as compared to neutral affect trials.

¹⁰ To speculate, if accuracy had been stressed over time, this would probably still have resulted in a shift toward more proactive control—which, however, might then have resulted in generally reduced error rates along with higher RTs, particularly on A-cue trials, and these effects could be most pronounced on AY trials.

highest priority. The effort decreasing effect of positive affect, on the other hand, should rather be dependent on safe benign situations (Schwarz, 1990, 2012) and should be easily disrupted by significant changes in the environment. Thus, it seems to serve an adaptive function that the influence of positive affect can be easily overridden by a highly prioritized mechanism like reward pursuit.

This vulnerability of positive affect effects to motivational influences explains conflicting results from the literature (e.g., Locke & Braver, 2008, vs. Dreisbach, 2006). Moreover, it is the first demonstration that positive affect effects on behavior can be eliminated by motivation, an effect that is of obvious importance in any applied (e.g., working or teaching) context in which rewards are given. For example, consistent with our results, studies on preschoolers showed that promising rewards for good performance enhanced goal-directed behavior, but decreased the ability to switch between different goals (Qu, Finestone, Qin, & Reena, 2013), whereas switching performance could be promoted by a positive affect manipulation (Wong, Jacques, & Zelazo, 2008). Likewise, research from the 80ies already provided evidence that creativity in children can be increased under positive affect (Greene & Noice, 1988), whereas performance-contingent rewards undermined creativity (Amabile, Hennessey, & Grossman, 1986). Thus, bearing in mind the vulnerability of positive affect effects, standard procedure in everyday school life (giving performance-contingent incentives in form of grades) should be reconsidered, whenever tasks require reactive control rather than proactive control. That is, the appropriate intervention to improve performance—performance-contingent reward or positive affect—obviously depends on the specific control demands of a given task and should therefore be chosen with caution.

Neuropsychological foundation of affect and reward

Although our results fit nicely with a growing body of empirical evidence showing diverging effects of performance-contingent reward and positive affect (cf. the reviews by Chiew & Braver, 2011, and Dreisbach & Fischer, 2012), the neuropsychological foundation of these effects is still under debate. With respect to reward, converging evidence exists that the neurotransmitter dopamine (DA) plays a prominent role (see, e.g., the reviews by Berridge, Robinson, & Aldridge, 2009; Cools, 2008; Schultz, 1997; and Wise & Rompre, 1989). In particular, current neuropsychological theories on cognitive control imply that reward-predicting stimuli elicit activity bursts of midbrain DA neurons into the prefrontal cortex (PFC; Cohen, Aston-Jones, & Gilzenrat, 2004; Miller & Cohen, 2001). This mechanism is assumed to work as a gating signal that triggers updating of representations within PFC and is sensitive to reward and reward predicting stimuli. More precisely, unexpected rewards or unexpected increases

in predicted rewards elicit further DA responses, whereas delays or decreases in predicted rewards inhibit DA responses, thereby strengthening or weakening currently active representations within PFC. That is, the DA gating system supports learning by reinforcement, which is assumed as the basis for adaptive updating.

In the neuropsychological theory of positive affect (Ashby et al., 1999; Ashby et al., 2002), this DA gating mechanism is proposed to enhance cognitive flexibility by facilitating selection of and switching between cognitive sets. In the DMC framework (Braver, 2012; Braver et al., 2007), on the other hand, it is assumed that a preceding DA gating signal is a necessary precondition for sustained activation of task representations in PFC. Therefore, the DA gating mechanism is proposed as the neuronal basis of proactive control, because without a gating signal only transient PFC activations (i.e., reactive control) are possible. The motivational reward effects in terms of increased proactive control presented here (in the performance-contingent reward conditions) and reported elsewhere (Chiew & Braver, 2013; Jimura et al., 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011) nicely fit with these assumptions. But what about positive affect effects? Are these also mediated by DA? From the intuitive relationship between positive affect and reward (the first being the affective consequence of the latter) both Braver (2012; Braver et al., 2007) and Ashby (Ashby et al., 1999, 2002) reasoned that positive affect might have comparable effects as reward—but with diverging predictions concerning the impact on proactive and reactive control. And there is indeed at least indirect evidence for a mediating role of DA in positive affect effects. Namely, a few studies (Dreisbach et al., 2005; Müller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011) investigated how individual differences in DA activity—indicated by the spontaneous eye blink rate (EBR; Elsworth et al., 1991)—influence cognitive control processes in a cognitive set switching task, a paradigm sensitive to positive affect modulations (Dreisbach & Goschke, 2004). Results over all three studies using the same paradigm consistently showed a “positive affect” performance pattern for participants with a higher EBR as compared to a low EBR. In particular, participants with a higher EBR (i.e., higher DA activity) showed enhanced cognitive flexibility accompanied by increased distractibility, just as the positive affect group in the original study (Dreisbach & Goschke, 2004). However, the results presented here stand in sharp contrast to the idea that positive affect and reward share common grounds with respect to the modulatory role of DA on cognitive control. By contrast, here we found oppositional effects of positive affect and reward. A possible solution to these obvious discrepancies on the role of DA within motivational and affective modulations of cognitive control could be the dual-state theory of PFC DA function by Durstewitz and Seamans (2008). Therein, the authors propose a dynamic balance between two distinct DA activity

systems—one D1-receptor dominated and the other D2-receptor dominated. Although the D1-receptor-dominated state is characterized by stable maintenance of currently active representations in PFC—comparable to the proactive control mode in the DMC framework—the D2-receptor-dominated state, on the other hand, promotes flexible and fast switching among representations—comparable to the reactive control mode. Thus, applied to our results, performance-contingent reward might have lead to a D1-receptor-dominated state, whereas performance-noncontingent reward and direct induction of positive affect might have resulted in a D2-receptor dominated state. Moreover, dissociations between mesocortical DA projections from ventral tegmental area into PFC, on the one side, and nigrostriatal DA projections from the substantia nigra into the striatum, on the other side, might also explain the diverging effects of reward and positive affect. Although DA activity in PFC is assumed to promote cognitive stability—that is, proactive control—DA activity in the striatum is associated with increased cognitive flexibility (Cools, 2008). Thus, applied to our results, the performance-contingent reward manipulation might have primarily influenced the mesocortical DA system, whereas positive affect (and random reward) might rather have influenced the nigrostriatal DA system. And indeed, Ashby et al. (1999) already speculated that nigrostriatal DA projections might be relevant for the cognitive effects of positive affect. In fact, this might be a way to disentangle the theoretical discrepancies between the neuropsychological theory of positive affect (Ashby et al., 1999, 2002) and the DMC framework (Braver, 2012; Braver et al., 2007).

A more recent review on the role of DA activity in cognitive control (Cools & D’Esposito, 2011) integrates the above mentioned theories on DA function (Cools, 2008; Durstewitz & Seamans, 2008) by taking into account that there are relatively fewer D2-receptors in PFC, but abundant D2-receptors in the striatum. Therefore, Cools and D’Esposito suggested two distinct DA systems with different functional roles: On the one hand, the D1 receptor dominated activity in PFC mediating stability (i.e., proactive control), and, on the other hand, the D2 receptor dominated activity in the striatum mediating flexibility (i.e., reactive control). More importantly, both systems are assumed to be reciprocally connected—that is, high activity in one system is accompanied by low activity in the other, and vice versa—which might explain why motivational effects under performance-contingent reward reduce positive affect effects on cognitive control. Moreover, the uncertainty of actually getting a reward or not in our performance-contingent reward manipulation might have led to more pronounced influences on DA activity, because especially unexpected rewards elicit strong DA responses (cf. Schultz, Dayan, & Montague, 1997).

But, of course, DA is not the only candidate to modulate cognitive control. For example, the neurotransmitter

norepinephrine (NE) has a modulatory influence on cognitive control well documented in the literature (Aston-Jones & Cohen, 2005a, b). Within this framework, phasic and tonic activity modes of NE are assumed to promote exploitative or explorative behavior, respectively, with the former being similar to behavior under proactive control. Of relevance regarding the neuropsychological background of positive affect and reward effects are furthermore findings from Berridge and colleagues (Berridge, 1996; Berridge et al., 2009; Smith, Berridge, & Aldridge, 2011) suggesting three distinguishable components of reward, namely “liking” (i.e., hedonic impact = positive affect), “wanting” (i.e., incentive salience = motivation), and learning (i.e., predictive associations and cognition), which are associated with distinct neuronal mechanisms. According to this theory, “liking” can be manipulated independent from “wanting” and vice versa, with not only DA being involved but also other neurotransmitters like opioids and glutamate. Taken together, several not mutually excluding theories exist that are consistent with the diverging behavioral effects of positive affect and reward presented here and elsewhere (cf. Chew & Braver, 2011; Dreisbach & Fischer, 2012).

Individual differences

In the present study, individual differences were apparent in reward responsiveness measures as measured by the respective BAS subscale. Participants in the PositiveReward group showed a positive correlation between total sum of received reward and individual BAS reward responsiveness scores, which was absent in the NeutralReward group (see Supplementary Materials, Tables S7–S10, for complete correlations with all BIS/BAS scales). Though both performance-contingent reward groups did not differ significantly in their mean total reward sums or BAS reward responsiveness scores, greater ranges of both individual scores emerged in the PositiveReward group (see Table 1). The positive correlation of received reward and BAS scores suggests that this variability might be a result of how people perceive rewards, at least to some extent. A motivational reward manipulation seems to have more effect—in terms of modifying behavior to successfully obtain rewards—on people, who are more sensitive toward reward. In line with this, previous studies (Jimura et al., 2010; Locke & Braver, 2008) showed positive correlations between individual reward sensitivity scores and global reward effects (RT facilitation in reward context or rate of obtained reward, respectively), and, moreover, reward sensitivity and modulations of brain activity, indicating a stronger shift toward proactive control from reward sensitive persons in rewarding contexts. Interestingly, in the present study, no such relationship was found in the NeutralReward group. This might be due to the differences in baseline performance between neutral and positive affect group. As compared to the positive group, the neutral group already in the baseline phase

showed relatively more proactive control. Thus, for these participants the introduction of performance-contingent reward in the second experimental phase was associated with less obvious performance changes. In the PositiveRewardGroup, by contrast, there was a clear strategy shift from less to more proactive control from baseline to reward phase possibly leaving more room for influences of individual reward sensitivity.

The importance of considering individual differences can also be seen in studies by Braem et al. (2012) and van Steenbergen et al. (2009), who both used reward manipulations without precues. Braem et al. (2012) found *increased* conflict adaption in an Eriksen flanker task following performance-contingent reward, and a positive correlation between this behavioral effect and all BAS subscales. In a similar task, van Steenbergen and colleagues (2009) found *reduced* conflict adaptation after performance-noncontingent, random reward, but also a positive correlation between BAS subscale drive and the conflict adaptation effect. This suggests that subjects with a strong drive to pursue rewards might generally put more effort into a given task irrespective of the reward contingency. Moreover, evidence in the literature suggests that the way a participant perceives the prospect of monetary reward—either as a demand signal to increase effort or as an easy opportunity to make some extra money—influences whether reward has rather motivational or affective effects. Müller and colleagues (2007b) investigated reward effects on cognitive control with a modified version of a cognitive set-switching task (Dreisbach & Goschke, 2004) and—in a post-experimental questionnaire—asked participants about their reward perception. The answers revealed that participants, who perceived the reward condition as demanding, showed a typical motivational effect with faster RTs and increased cognitive stability (i.e., proactive control). In contrast, participants, who perceived the reward as an easy gain, showed a typical “positive affect” response pattern with increased cognitive flexibility and reduced stability. It thus seems that subjective reward perception also modulates the motivational versus affective impact that reward can have on performance. In the study presented here, the effort-demanding character of performance-contingent reward—which is obviously absent in the random, performance-noncontingent reward manipulation—might be what caused the transition from an affective to a predominantly motivational effect. In sum, the present and previous results (e.g., Jimura et al., 2010; Locke & Braver, 2008; Müller, Dreisbach, Goschke, et al., 2007) demonstrate that individual differences in reward sensitivity and reward perception further influence how affective and motivational manipulations modulate cognitive control.

Comment on Chiew and Todd (2014)

Finally we would like to take the opportunity to address the study by Chiew and Todd (2014), in which the authors also

have shown comparable reward effects in terms of significantly increased AY errors. However, and in sharp contrast to our results, the authors did not find any positive affect effect—or if one did occur, it was even in the opposite direction. One reason for this discrepancy might be the specific affect manipulation used by the authors. It is possible that the positive film clip induced a positive mood that was then not further modulated by the positive versus neutral picture stimuli in the emotion block to follow.¹¹ From a theoretical perspective, this might of course point to the interesting idea that in contrast to reward, which can have sustained and transient effects (as evidenced by the difference in performance between incentive and nonincentive trials first presented by Chiew and Braver, 2013, and in part replicated here), affect effects cannot easily be turned on and off. If we assume that reward effects are mainly motivational and that affect effects are rather emotional, it seems intuitively plausible that this may indeed be the case. Of course, at this point, this speculation awaits further investigation. Another reason for the discrepant results might be the specific AX procedure that we applied. Note that—in contrast to Chiew and Todd (2014)—we presented distractors between the cue and probe in order to increase proactive control demands. Increasing proactive control demands of course leaves more room for the (down)modulation of proactive control by positive affect. This also is in line with the idea that positive affect increases distractibility, which might go along with reduced proactive control (e.g., Dreisbach & Goschke, 2004). Finally, our own data show that positive affect effects obviously are vulnerable to strategic motivational influences (in the PositiveReward group). This observation of course should not be taken as a convenient measure to explain discrepant results within the existing literature, but should first and foremost guide future research in finding ways to disentangle motivational from emotional modulations of cognitive control (see also Gable & Harmon-Jones, 2008, 2010).¹²

Conclusion

Positive affect arises in a variety of situations—for example, as a consequence of direct affect induction, performance-contingent reward, or noncontingent reward. However, recent evidence from independent research lines indicated diverging effects of positive affect and reward on cognitive control, with the former being affective and the latter motivational (cf.

¹¹ Note that the comparison between the emotion block and the respective baseline block is confounded with practice and/or strategic knowledge about the task, and therefore is not easy to interpret.

¹² Gable and Harmon-Jones (2008, 2010) differentiated between low- and high-approach-motivated emotions (e.g., joy vs. desire) and found that these different emotions had opposite effects on attention (broadening vs. narrowing).

Chiew & Braver, 2011; Dreisbach & Fischer, 2012). The combined investigation of positive affect and reward manipulations in a single study presented here showed that both differentially modulate processes of cognitive control: (1) Only performance-contingent reward but not random, non-contingent reward had a motivational effect. (2) Performance-contingent reward increased proactive control, whereas positive affect and random reward reduced proactive control and increased reactive control. (3) Combining both experimental manipulations revealed that motivational influences outweigh affective influences. It will be an interesting endeavor for future research to show how these opposing affect and motivation effects generalize across different tasks and situations.

Appendix

Table 2 IAPS picture selection for the two affect conditions

IAPS Number	
Neutral	Positive
7000	1440
7004	1710
7006	1750
7009	1920
7035	2057
7040	2150
7080	2260
7090	2311
7175	2340
7233	2530

References

- Amabile, T. M., Hennessey, B. A., & Grossman, B. S. (1986). Social influences on creativity: The effects of contracted-for reward. *Journal of Personality and Social Psychology, 50*, 14–23. doi:10.1037/0022-3514.50.1.14
- Ashby, F. G., Isen, A. M., & Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*, 529–550. doi:10.1037/0033-295X.106.3.529
- Ashby, F. G., Valentin, V. V., & Turken, U. (2002). The effects of positive affect and arousal on working memory and executive attention. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behaviour* (pp. 245–287). Amsterdam, The Netherlands: John Benjamins.
- Aston-Jones, G., & Cohen, J. D. (2005a). Adaptive gain and the role of the locus coeruleus–norepinephrine system in optimal performance. *Journal of Comparative Neurology, 493*, 99–110. doi:10.1002/cne.20723
- Aston-Jones, G., & Cohen, J. D. (2005b). An integrative theory of locus coeruleus–norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28*, 403–450. doi:10.1146/annurev.neuro.28.061604.135709
- Berridge, K. C. (1996). Food reward: Brain substrates of wanting and liking. *Neuroscience & Behavioral Reviews, 20*, 1–25. doi:10.1016/0149-7634(95)00033-B
- Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: “Liking”, “wanting”, and learning. *Current Opinion in Pharmacology, 9*, 65–73. doi:10.1016/j.coph.2008.12.014
- Bijleveld, E., Custers, R., & Aarts, H. (2012a). Adaptive reward pursuit: How effort requirements affect unconscious reward responses and conscious reward decisions. *Journal of Experimental Psychology: General, 141*, 728–742. doi:10.1037/a0027615
- Bijleveld, E., Custers, R., & Aarts, H. (2012b). Human reward pursuit: From rudimentary to higher-level functions. *Current Directions in Psychological Science, 21*, 194–199. doi:10.1177/0963721412438463
- Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2013). Affective modulation of cognitive control is determined by performance-contingency and mediated by ventromedial prefrontal and cingulate cortex. *Journal of Neuroscience, 33*, 16961–16970. doi:10.1523/JNEUROSCI.1208-13.2013
- Braem, S., Verguts, T., Roggeman, C., Notebaert, W., & Roggeman, C. (2012). Reward modulates adaptations to conflict. *Cognition, 125*, 324–332. doi:10.1016/j.cognition.2012.07.015
- Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*, 106–113. doi:10.1016/j.tics.2011.12.010
- Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). Oxford, UK: Oxford University Press.
- Carver, C. S. (2003). Pleasure as a sign you can attend to something else: Placing positive feelings within a general model of affect. *Cognition and Emotion, 17*, 241–261. doi:10.1080/02699930302294
- Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology, 67*, 319–333. doi:10.1037/0022-3514.67.2.319
- Chiew, K. S., & Braver, T. S. (2011). Positive affect versus reward: Emotional and motivational influences on cognitive control. *Frontiers in Psychology, 2*, 279. doi:10.3389/fpsyg.2011.00279
- Chiew, K. S., & Braver, T. S. (2013). Temporal dynamics of motivation–cognitive control interactions revealed by high-resolution pupillometry. *Frontiers in Psychology, 4*, 15. doi:10.3389/fpsyg.2013.00015
- Chiew, K. S., & Todd, S. B. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective, & Behavioral Neuroscience*. doi:10.3758/s13415-014-0280-0
- Codispoti, M., Mazzeti, M., & Bradley, M. M. (2009). Unmasking emotion: Exposure duration and emotional engagement. *Psychophysiology, 46*, 731–738. doi:10.1111/j.1469-8986.2009.00804.x
- Cohen, J. D., Aston-Jones, G., & Gilzenrat, M. S. (2004). A systems-level perspective on attention and cognitive control: Guided activation, adaptive gating, conflict monitoring, and exploitation versus exploration. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 71–90). New York, NY: Guilford Press.
- Cools, R. (2008). Role of dopamine in the motivational and cognitive control of behavior. *Neuroscientist, 14*, 381–395. doi:10.1177/1073858408317009
- Cools, R., & D’Esposito, M. (2011). Inverted-U shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry, 69*, e113–e125. doi:10.1016/j.biopsych.2011.03.028
- Dreisbach, G. (2006). How positive affect modulates cognitive control: The costs and benefits of reduced maintenance capability. *Brain and Cognition, 60*, 11–19. doi:10.1016/j.bandc.2005.08.003

- Dreisbach, G., & Fischer, R. (2012). The role of affect and reward in the conflict-triggered adjustment of cognitive control. *Frontiers in Human Neuroscience*, 6, 342. doi:10.3389/fnhum.2012.00342
- 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*, 30, 343–353. doi:10.1037/0278-7393.30.2.343
- Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K.-P., & Brocke, B. (2005). Dopamine and cognitive control: The influence of spontaneous eyeblink rate and dopamine gene polymorphisms on perseveration and distractibility. *Behavioral Neuroscience*, 119, 483–490. doi:10.1037/0735-7044.119.2.483
- Durstewitz, D., & Seamans, J. K. (2008). The dual-state theory of prefrontal cortex dopamine function with relevance to Catechol-O-Methyltransferase genotypes and schizophrenia. *Biological Psychiatry*, 64, 739–749. doi:10.1016/j.biopsych.2008.05.015
- Eitam, B., Kennedy, P. M., & Higgins, E. T. (2013). Motivation from control. *Experimental Brain Research, Advance online publication*. doi:10.1007/s00221-012-3370-7
- Elsworth, J. D., Lawrence, M. S., Roth, R. H., Taylor, J. R., Mailman, R. B., Nichols, D. E., & Redmond, D. E., Jr. (1991). D₁ and D₂ dopamine receptors independently regulate spontaneous blink rate in the vervet monkey. *Journal of Pharmacology and Experimental Therapeutics*, 259, 595–600.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, 16, 143–149. doi:10.3758/BF03203267
- Fröber, K., & Dreisbach, G. (2012). How positive affect modulates proactive control: Reduced usage of informative cues under positive affect with low arousal. *Frontiers in Psychology*, 3, 265. doi:10.3389/fpsyg.2012.00265
- Gable, P. A., & Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention. *Psychological Science*, 19, 476–482. doi:10.1111/j.1467-9280.2008.02112.x
- Gable, P. A., & Harmon-Jones, E. (2010). The blues broaden, but the nasty narrows: Attentional consequences of negative affects low and high in motivational intensity. *Psychological Science*, 21, 211–215. doi:10.1177/0956797609359622
- Greene, T. R., & Noice, H. (1988). Influence of positive affect upon creative thinking and problem solving in children. *Psychological Reports*, 63, 895–898. doi:10.2466/pr0.1988.63.3.895
- Hull, C. L. (1943). *Principles of behavior*. New York, NY: Appleton-Century.
- Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences*, 107, 8871–8876. doi:10.1073/pnas.1002007107
- Kleinsorge, T., & Rinkenauer, G. (2012). Effects of monetary incentives on task switching. *Experimental Psychology*, 59, 216–226. doi:10.1027/1618-3169/a000146
- Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, 139, 665–682. doi:10.1037/a0020198
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *International Affective Picture System (IAPS): Technical manual and affective ratings* (Technical Report No. A-2). Gainesville, FL: University of Florida, Center for Research in Psychophysiology.
- Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective, & Behavioral Neuroscience*, 8, 99–112. doi:10.3758/CABN.8.1.99
- Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, 24, 167–202. doi:10.1146/annurev.neuro.24.1.167
- Müller, J., Dreisbach, G., Brocke, B., Lesch, K.-P., Strobel, A., & Goschke, T. (2007a). Dopamine and cognitive control: The influence of spontaneous eyeblink rate, DRD4 exon III polymorphism and gender on flexibility in set-shifting. *Brain Research*, 1131, 155–162. doi:10.1016/j.brainres.2006.11.002
- Müller, J., Dreisbach, G., Goschke, T., Hensch, T., Lesch, K.-P., & Brocke, B. (2007b). Dopamine and cognitive control: the prospect of monetary gains influences the balance between flexibility and stability in a set-shifting paradigm. *European Journal of Neuroscience*, 26, 3661–3668. doi:10.1111/j.1460-9568.2007.05949.x
- Padmala, S., & Pessoa, L. (2011). Reward reduces conflict by enhancing attentional control and biasing visual cortical processing. *Journal of Cognitive Neuroscience*, 23, 3419–3432. doi:10.1162/jocn_a_00011
- Qu, L., Finestone, D. L., Qin, L. J., & Reena, L. Z. (2013). Focused but fixed: The impact of expectation of external rewards on inhibitory control and flexibility in preschoolers. *Emotion*, 13, 562–572. doi:10.1037/a0027263
- Satterthwaite, T. D., Ruparel, K., Loughead, J., Elliot, M. A., Gerraty, R. T., Calkins, M. E., & Wolf, D. H. (2012). Being right is its own reward: Load and performance related ventral striatum activation to correct responses during a working memory task in youth. *NeuroImage*, 61, 723–729. doi:10.1016/j.neuroimage.2012.03.060
- Schultz, W. (1992). Activity of dopamine neurons in the behaving primate. *Seminars in Neuroscience*, 4, 129–138. doi:10.1016/1044-5765(92)90011-P
- Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*, 275, 1593–1599. doi:10.1126/science.275.5306.1593
- Schwarz, N. (1990). Feeling as information: Informational and motivational functions of affective states. In R. M. Sorrentino & E. T. Higgins (Eds.), *Handbook of motivation and cognition: Foundations of social behavior* (2nd ed., pp. 527–561). New York, NY: Guilford Press.
- Schwarz, N. (2012). Feeling-as-Information theory. In P. A. M. van Lange, A. W. Kruglanski, & E. T. Higgins (Eds.), *Handbook of theories of social psychology* (Vol. 1, pp. 289–308). London, UK: Sage.
- 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. doi:10.1001/archpsyc.1996.01830120037008
- Smith, K. S., Berridge, K. C., & Aldridge, J. W. (2011). Disentangling pleasure from incentive salience and learning signals in brain reward circuitry. *Proceedings of the National Academy of Sciences*, 108, E255–E264. doi:10.1073/pnas.1101920108
- Strobel, A., Beauducel, A., Debener, S., & Brocke, B. (2001). Eine deutschsprachige Version des BIS/BAS-Fragebogens von Carver und White. *Zeitschrift für Differentielle und Diagnostische Psychologie*, 22, 216–227.
- Stürmer, B., Nigbur, R., Schacht, A., & Sommer, W. (2011). Reward and punishment effects on error processing and conflict control. *Frontiers in Psychology*, 2, 335. doi:10.3389/fpsyg.2011.00335
- Tharp, I. J., & Pickering, A. D. (2011). Individual differences in cognitive flexibility: The influence of spontaneous eyeblink rate, trait psychoticism and working memory on attentional set-shifting. *Brain and Cognition*, 75, 119–125. doi:10.1016/j.bandc.2010.10.010
- van Steenbergen, H., Band, G. P. H., & Hommel, B. (2009). Reward counteracts conflict adaptation: Evidence for a role of affect in executive control. *Psychological Science*, 20, 1473–1477. doi:10.1111/j.1467-9280.2009.02470.x
- van Steenbergen, H., Band, G. P. H., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science*, 21, 1629–1634. doi:10.1177/0956797610385951
- van Steenbergen, H., Band, G. P., & Hommel, B. (2012). Reward valence modulates conflict-driven attentional adaptation: Electrophysiological

- evidence. *Biological Psychology*, *90*, 234–241. doi:10.1016/j.biopsycho.2012.03.018
- van Wouwe, N. C., Band, G. P. H., & Ridderinkhof, K. R. (2011). Positive affect modulates flexibility and evaluative control. *Journal of Cognitive Neuroscience*, *23*, 524–539. doi:10.1162/jocn.2009.21380
- Wise, R. A., & Rompre, P.-P. (1989). Brain dopamine and reward. *Annual Review of Psychology*, *40*, 191–225. doi:10.1146/annurev.ps.40.020189.001203
- Wong, S. S., Jacques, S., & Zelazo, P. D. (2008). A preliminary investigation of the effects of emotional stimuli on 4-year-old children's abstraction and cognitive flexibility on the flexible item selection task (FIST). *Journal of Undergraduate Life Sciences*, *2*, 34–42.
- Zedelius, C. M., Veling, H., Bijleveld, E., Aarts, H., & Daunizeau, J. (2012). Promising high monetary rewards for future task performance increases intermediate task performance. *PLoS ONE*, *7*, e42547. doi:10.1371/journal.pone.0042547