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Research Report

Reward Counteracts Conflict Adaptation

Evidence for a Role of Affect in Executive Control

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ABSTRACT—*The conflict-adaptation effect has been observed in several executive-control tasks and is thought to reflect an increase in control, driven by experienced conflict. We hypothesized that if this adaptation originates from the aversive quality of conflict, it would be canceled out by a positive, rewarding event. Subjects performed an arrow flanker task with monetary gain or loss as arbitrary feedback between trials. As predicted, we found a reduction in conflict adaptation for trials in which conflict was followed by monetary gain. The strength of this gain-induced modulation was found to depend on subjects' motivation to pursue reward, as measured by the Behavioral Activation System Drive scale. Our findings demonstrate for the first time that the conflict-adaptation effect can be strongly reduced by reward contexts, suggesting that reward and conflict can compensate for each other's effects, probably via changes in dopamine levels.*

In decision making, the heart is the adversary of the mind—at least according to folk wisdom. Emotions are commonly believed to create irrational behavior and to lead to wrong judgments. However, there is increasing evidence that emotion and cognition often cooperate in shaping adaptive behavior and that a dysfunction of emotional processing impairs rational reasoning and action control (e.g., Damasio, 1994). Considerable research effort has focused on the impact of longer term emotional states (i.e., mood) on cognitive functioning, and there is evidence that, for instance, positive mood improves performance in various cognitive tasks (Ashby, Isen, & Turken, 1999) and affects cognitive-control operations in systematic ways (Dreisbach & Goschke, 2004). However, recent observations suggest that even very brief affective states are associated with adaptations in cognitive control and may thus be involved in tailoring control strategies to the situation at hand. This seems particularly true for states induced by aversive and rewarding events, presumably because such events directly affect the current level of dopamine (Schultz, 2007), a neurotransmitter that plays an important role in regulating the (frontal) brain areas underlying cognitive control (Miller & Cohen, 2001).

One important function of cognitive control is to adapt control parameters to current task requirements. It is assumed that the adaptation of such parameters is, or at least can be, driven by the registration of conflict (e.g., between competing responses; Botvinick, Braver, Barch, Carter, & Cohen, 2001). Evidence supporting this view comes from tasks in which participants need to focus on a relevant target while ignoring distracting information (cf. Egner, 2007, for a review). For example, in the flanker task (Eriksen & Eriksen, 1974), congruent (C) flankers are known to facilitate, and incongruent (I) flankers to interfere with, speeded responses to the central target. This congruency effect is modulated by the amount of conflict perceived on the preceding trial. Gratton, Coles, and Donchin (1992), who reported this effect originally, argued that participants focus their attention more on the target after an incongruent trial (i), which reduces the congruency effect (I − C) in the next trial (iI − iC), as compared with trials following a congruent trial (cI − cC). This effect has been called the "conflict-adaptation effect" because it is believed to reflect adjustments in cognitive control that are driven by conflict information (Botvinick et al., 2001). Although episodic memory retrieval of stimulus and response associations may account for some of the published findings (Hommel, Proctor, & Vu, 2004), more recent studies suggest that control-related portions of the effect remain, even if episodic effects are controlled for (Egner, 2007).

Botvinick (2007) has recently suggested that conflict may be experienced as an aversive, or negatively reinforcing, event. It may thus be the aversive quality of a conflict that signals the

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need for adjustment to cognitive-control systems, which then respond by refreshing or strengthening the representation of the current intention or goal. If the need for control is indeed signaled by an aversive (negative) event—so we reasoned in the present study—it should be possible to counteract control operations by presenting a rewarding, positive event at about the same time. This is what we tried to do by signaling an unexpected monetary gain. The idea was that this reward cue might outweigh the conflict-induced control signal and prevent behavioral adaptation.

Applying this reasoning to the conflict-adaptation effect, we predicted that the presentation of a rewarding stimulus immediately after an incongruent trial would reduce conflict-driven adaptation in the next trial. This was tested in an otherwise standard flanker task by providing unpredictable monetary gains or losses during the response-stimulus interval. According to our prediction, the conflict-adaptation effect would be diminished in the gain condition as compared with the loss condition. We also included neutral trials, without gain or loss, to demonstrate normal conflict-adaptation effects in a standard, emotionally neutral context.[1]

Our second prediction considered that the effect of the gain manipulation may depend on individual sensitivity to reward. Gray (1989) suggested that a Behavioral Activation System (BAS) may guide behavior in response to reward signals via the dopamine system. Based on his work, self-report BAS scales have been developed to describe BAS activation as a personality dimension (Carver & White, 1994). Previous research has shown that the BAS Drive and BAS Reward Responsiveness scales predict hedonic responses and behavioral regulation in response to reward and can be used as a reliable index of trait reward sensitivity (e.g., Carver & White, 1994; Franken & Muris, 2006). If our gain condition reduces conflict adaptation in general, individuals who score high on these scales would thus be more likely than individuals who scored low to show particularly strong reductions.

METHOD

Participants

Thirty-three university students participated (18–30 years of age; 8 men and 25 women). They were informed about the duration of the experiment (15 min) and that they would earn €2, plus a bonus that could increase to a few euros if they were lucky. One subject was excluded from analyses because of response omissions on more than 10% of the trials.

Procedure

Instructions were given on a computer screen. Subjects were informed about the task and that smiley, sad, and neutral faces would appear between trials independently of their responses. The computer would add €0.20 to their bonus if a smiley face appeared and would subtract €0.20 if a sad face appeared. Neutral faces were not associated with any gain or loss. Subjects were encouraged to make quick and accurate responses with their index fingers on the keyboard, to the central target of an arrow flanker stimulus. After giving consent, participants performed 24 practice trials and were given accuracy feedback for 600 ms at the end of each trial. Then they were given the opportunity to read the instructions again, and they were informed about the three test blocks in which they would earn money, each lasting about 4 min. Self-paced break screens with a maximum duration of 40 s were shown in between. We did not tell the subjects that the last test block annexed a filler block of 24 trials, where gain trials were overrepresented. This resulted in a random bonus payoff of between €0.40 and €2.00 for each person.

The stimuli were presented on a white background on a 15-in. monitor, and participants viewed the monitor from a distance of about 60 cm. Each of the 612 test trials started with a fixation cross (for varying intervals of 200, 300, and 400 ms), followed by the flanker stimulus. Immediately after a response to the flanker stimulus or, in the case of omission, after 1,000 ms, a line-drawn face was presented for 500 ms, after which the next trial started. Flanker stimuli comprised a row of five black arrows pointing either left or right. We used the same number of congruent (flankers in the same direction as the target) and incongruent (flankers opposite to the target) trials. Smiley, sad, and neutral faces were distributed uniformly and served as cues for monetary gain or loss.

Scales

A subset of 22 participants had filled out questionnaires in an earlier unrelated experiment. To explore associations with reward-related traits (measured with the BAS scales) and reward-unrelated traits (measured with other scales), individual scale scores were correlated with conflict-adaptation latency effects for the gain condition. We used the following trait scales translated into Dutch: the Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) Scales (Franken, Muris, & Rassin, 2005), the Positive and Negative Affect Schedule (Hill, van Boxtel, Ponds, Houx, & Jolles, 2005), the Eysenck Personality Questionnaire (Sanderman, Arrindell, Ranchor, Eysenck, & Eysenck, 1995), and the Action Control Scale (Koole & Jostmann, 2004). To provide a safeguard against multiple testing, we used a conservative criterion ($\alpha = .01$) for significant correlations. Because only one subscale from the BIS/BAS Scales was significantly correlated with performance, scores from the other reward-unrelated scales are not further considered here.

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[1] One may speculate that loss might increase the conflict-adaptation effect beyond what can be observed with neutral trials: Loss may increase the aversiveness of the situation and therefore support or strengthen the conflict signal. However, it is not clear whether aversiveness can be further increased by our manipulation or whether conflict in the neutral condition leads to some maximum aversion limit already—so we hesitated to predict differences between the loss and the neutral condition.

Data Analysis

We used repeated measures analyses of variance and t tests to analyze correct reaction time (RT) and error rates for test trials, as a function of the congruency of the current trial (I vs. C); the congruency of the previous trial (i vs. c); and the reward signal (gain, neutral, or loss), shown as feedback in the previous trial. The first trial of each block (0.5%), trials following an error (5.9%), and trials with RTs not fitting the outlier criterion (2.5 *SD*; 2.6%) were excluded from analysis.

RESULTS

As usually found, performance on the flanker task was faster (415 ms vs. 458 ms), $F(1, 31) = 316.23$, $p_{\text{rep}} = .99$, $d = 4.52$, and more accurate (2.3% vs. 8.2% errors), $F(1, 31) = 84.54$, $p_{\text{rep}} = .99$, $d = 2.34$, on congruent than on incongruent trials. Moreover, as predicted, normal conflict-adaptation latency effects were found for the neutral and loss conditions, respectively, $F(1, 31) = 7.83$, $p < .01$, $p_{\text{rep}} = .95$, $d = 0.71$; $F(1, 31) = 13.96$, $p < .001$, $p_{\text{rep}} = .99$, $d = 0.95$, whereas no evidence for this effect was found for the gain condition, $F(1, 31) = 0.03$, $p > .05$, $p_{\text{rep}} = .21$, $d = 0.04$ (see Table 1). A direct comparison of conflict-adaptation effects, $(\text{RT}_{\text{cI}} - \text{RT}_{\text{cC}}) - (\text{RT}_{\text{iI}} - \text{RT}_{\text{iC}})$, for the gain and the loss conditions confirmed the predicted effect, $t(31) = 1.844$, $p < .05$, $p_{\text{rep}} = .85$, $d = 0.49$. Analyses on high-conflict (iI) versus low-conflict (cI) trials also illustrate this influence of gain context, $F(2, 62) = 3.59$, $p < .05$, $p_{\text{rep}} = .90$, $d = 0.48$ (see Table 1 for details): Normal conflict-driven speedup was found for the loss (6 ms) and neutral (5 ms) conditions, whereas in the gain condition, this effect disappeared (−3 ms). Explanations suggesting an influence of gain that is independent of previous-trial conflict could be ruled out, given that gain on the previous trial was not associated with overall response slowing, $F(2, 62) = 0.72$, $p > .05$, $p_{\text{rep}} = .51$, $d = 0.22$, or increases in congruency effects on the next trial, $F(2, 62) = 0.57$, $p > .05$, $p_{\text{rep}} = .45$, $d = 0.19$. Comparable results were obtained for the error-rate data (see Table 1).

To test our second prediction, BIS/BAS subscale scores were correlated with the conflict-adaptation latency effect in the gain condition. As shown in Figure 1, individual BAS Drive scores (possible range from 4 to 16) strongly predicted a gain-induced decrease in conflict adaptation ($r = -.576$, $p < .005$, $p_{\text{rep}} = .97$). The other subscales (BIS, BAS Reward Responsiveness, and BAS Fun Seeking) were not associated with this measure (*p*s > .05), nor were any correlations found for the neutral and loss conditions (*p*s > .10).

DISCUSSION

Our results demonstrate for the first time that unexpected monetary gain leads to a strong reduction of conflict-driven adaptation. This observation is in keeping with the assumption

TABLE 1

Congruency and Conflict-Adaptation Effects as a Function of Condition

Trial type	Latency (ms)	Error rate (%)
Gain condition		
Congruent trial following a congruent trial (cC)	413	2.3
Congruent trial following an incongruent trial (iC)	416	1.9
Incongruent trial following a congruent trial (cI)	457	9.1
Incongruent trial following an incongruent trial (iI)	460	8.3
Congruency effect	44**	6.6**
Conflict-adaptation effect	1	0.3
Neutral condition		
Congruent trial following a congruent trial (cC)	413	2.1
Congruent trial following an incongruent trial (iC)	418	2.9
Incongruent trial following a congruent trial (cI)	461	8.8
Incongruent trial following an incongruent trial (iI)	456	7.4
Congruency effect	43**	5.6**
Conflict-adaptation effect	9**	2.2*
Loss condition		
Congruent trial following a congruent trial (cC)	412	2.1
Congruent trial following an incongruent trial (iC)	417	2.5
Incongruent trial following a congruent trial (cI)	459	8.7
Incongruent trial following an incongruent trial (iI)	453	7.1
Congruency effect	42**	5.6**
Conflict-adaptation effect	10**	2.0†

Note. The congruency effect was calculated from reaction times or error rates according to the following formula: (cI + iI)/2 − (cC + iC)/2. The conflict-adaptation effect was calculated as follows: (cI − cC) − (iI − iC). Simple-effects t tests were used to identify congruency and conflict-adaptation effects significantly different from 0.

†$p < .1$. *$p < .05$. **$p < .01$.

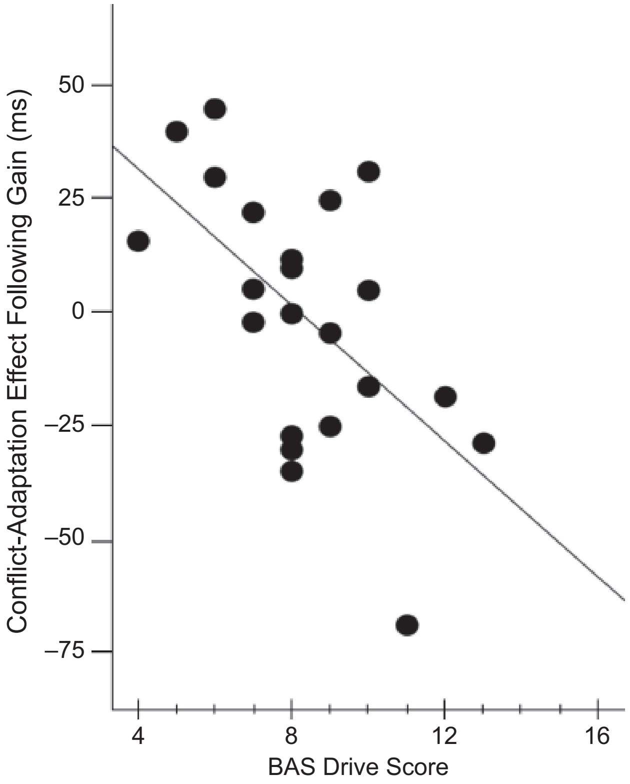

Fig. 1. Scatter plot showing the association between scores on the Behavioral Activation System (BAS) Drive scale and individual conflict-adaptation effects in the gain condition ($r = -.576$).

that (a) response conflict may be experienced as an aversive event that signals the need for adaptive control (Botvinick, 2007); (b) unexpected monetary gain represents a positive, rewarding event; and (c) the effects of these two events can cancel each other out. The observation that the effects of rewarding and aversive events can compensate for each other suggests some common currency, some shared dimension on which positivity and negativity can be directly compared. We suggest that the dopamine system may provide this common currency, which is consistent with earlier findings showing that rewarding events involve phasic increases in dopamine level (Schott et al., 2008; Schultz, 2007), whereas decreases are associated with aversive events, including conflicts (Jocham & Ullsperger, 2009; Schultz, 2007). A dopaminergic modulation is also suggested by our observation that individual differences in reward sensitivity predict the influence of gain on conflict-driven adaptation. Interestingly, only the individual goal-directed drive to pursue reward (as measured by BAS Drive) was involved in this modulation, whereas differences in hedonic responsiveness to reward (as measured by BAS Reward Responsiveness) were not. A similar pattern has been observed for dopamine responses to rewarding stimuli (Beaver et al., 2006). These findings suggest a dominant modulating role for the motivational rather than the hedonic aspect of reward, which presumably involves dopamine (Berridge & Robinson, 2003).

Future work, including brain imaging, may reveal the underlying mechanisms of conflict adaptation, reward processing, and their interactions. It would be interesting to study the performance of clinical samples as well. People with depression, for instance, may show smaller reductions in the gain condition because of their lower responsiveness to reward (Nestler & Carlezon, 2006), an effect that may interact with general changes in conflict adaptation as well (cf. Mansouri, Tanaka, & Buckley, 2009; Holmes & Pizzagalli, 2007).

Taken all together, our observations support the idea that emotion and cognition need to cooperate to generate adaptive behavior. That is, the affective quality of an event provides important information about the amount and type of executive control needed to make sure that goals are reached as planned. Conflict-adaptation studies from the past have shown that increased control is a natural response to conflicts. However, people have a desire for rewards and—as demonstrated in this article—once they get them, their control system relaxes immediately.

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Erratum

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An error in the BIS/BAS scale calculation resulted in the incorrect publication of a reversed score and correlation. To represent the data correctly, the values on the horizontal axis of Figure 1 should have run from 16 to 4, and the figure caption should have reported "r = .576." The sentence on p. 1475 that reads "individual BAS Drive scores . . . strongly predicted a gain-induced decrease in conflict adaptation (r = −.576 . . .)" should have stated, "individual BAS Drive scores . . . strongly predicted a gain-induced increase in conflict adaptation (r = .576 . . .)." On p. 1476, after "These findings suggest a dominant modulating role for the motivational rather than the hedonic aspect of reward, which presumably involves dopamine (Berridge & Robinson, 2003)," the following sentence should have been added: "However, because the direction of this motivation modulation was opposite to the main compensatory effect of reward on conflict-driven control, the presumed role of dopamine in this modulation needs further study."