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Emotional modulation of control dilemmas: The role of positive affect, reward, and dopamine in cognitive stability and flexibility

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ABSTRACT

Goal-directed action in changing environments requires a dynamic balance between complementary control modes, which serve antagonistic adaptive functions (e.g., to shield goals from competing responses and distracting information vs. to flexibly switch between goals and behavioral dispositions in response to significant changes). Too rigid goal shielding promotes stability but incurs a cost in terms of perseveration and reduced flexibility, whereas too weak goal shielding promotes flexibility but incurs a cost in terms of increased distractibility. While research on cognitive control has long been conducted relatively independently from the study of emotion and motivation, it is becoming increasingly clear that positive affect and reward play a central role in modulating cognitive control. In particular, evidence from the past decade suggests that positive affect not only influences the contents of cognitive processes, but also modulates the balance between complementary modes of cognitive control. In this article we review studies from the past decade that examined effects of induced positive affect on the balance between cognitive stability and flexibility with a focus on set switching and working memory maintenance and updating. Moreover, we review recent evidence indicating that task-irrelevant positive affect and performance-contingent rewards exert different and sometimes opposite effects on cognitive control modes, suggesting dissociations between emotional and motivational effects of positive affect. Finally, we critically review evidence for the popular hypothesis that effects of positive affect may be mediated by dopaminergic modulations of neural processing in prefrontal and striatal brain circuits, and we refine this "dopamine hypothesis of positive affect" by specifying distinct mechanisms by which dopamine may mediate effects of positive affect and reward on cognitive control. We conclude with a discussion of limitations of current research, point to central unresolved questions and outline perspective for future research on affective and motivational modulations of cognitive control modes.

1. Introduction

The term cognitive control denotes a heterogeneous set of mechanisms that underlie the human ability to configure behavioral dispositions according to superordinate goals or task instructions, to maintain goals in the face of distraction, and to suppress prepotent, but unwanted habitual or impulsive responses (Banich, 2009; Goschke, 2013; Miller & Cohen, 2001). Although in the past two decades substantial progress has been made in elucidating the factor structure (e.g., Friedman et al., 2008; Miyake et al., 2000), computational mechanisms (e.g., O'Reilly, Herd, & Pauli, 2010), and neural basis (e.g., Mars, Sallet, Rushworth, & Yeung, 2011) of cognitive control, it is still insufficiently understood how cognitive control processes are modulated by emotional and motivational factors. While research on cognitive control has long been conducted relatively independently from the study of emotions, it becomes increasingly clear that brain systems involved in cognitive control such as the prefrontal cortex (PFC) are strongly interconnected with brain systems involved in the processing of emotion and motivation (Banich et al., 2009; Chiew & Braver, 2011; Mars et al., 2011; Pessoa, 2009; Ray & Zald, 2012). However, in contrast to a voluminous body of research on effects of emotions and moods on perception, attention, and creative problem-solving (for reviews see Bolte & Goschke, 2010; Fredrickson, 2013; Friedman & Förster, 2010; Isen, 2007), research on how emotions specifically modulate cognitive control processes has only recently gained momentum (e.g., Banich et al., 2009; Bolte & Goschke, 2010; Chiew & Braver, 2011; Dreisbach & Fischer, 2012; Mitchell & Phillips, 2007; Mueller, 2011). Importantly, findings obtained during the past decade have revealed that emotions not only influence the contents of cognitive control processes (e.g., which goals are maintained in working memory), but also modulate the *mode* of cognitive control (e.g., how strongly goals are shielded from distraction or how flexibly cognitive sets are updated).

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1.1. Scope of the present review

In this review we focus specifically on effects of induced positive affect on complementary cognitive control modes and, in particular, the balance between stable maintenance and flexible shifting of goals and task-sets. Our guiding hypothesis is that emotions are associated with different settings of "meta-control parameters" that regulate the balance between complementary control modes and thereby promote either flexible switching or stable maintenance of goals and cognitive sets. While our primary focus is on positive affect, we also provide a selective review of recent evidence indicating that *task-irrelevant* positive affect and *performance-contingent* rewards exert markedly different and sometimes opposite effects on cognitive control modes. This discussion complements recent reviews on the role of positive affect and reward in other domains of cognitive control such as conflict monitoring (Chiew & Braver, 2011; Dreisbach & Fischer, 2012). Our second main aim is to discuss possible computational and neural mechanisms that may mediate emotional modulations of cognitive control modes. In particular, we critically review evidence for the popular hypothesis that effects of positive affect on cognitive control are mediated by dopaminergic modulations of neural processing in frontal-striatal brain circuits (e.g., Ashby, Isen, & Turken, 1999; Ashby, Valentin, & Turken, 2003).

Note that it is neither our aim to provide a comprehensive overview of emotional modulations of cognitive processes *in general* nor to review effects of emotions on *all* aspects of cognitive control. Rather, we restrict the scope of this review to studies that have examined effects of positive affect (or reward) on task-set switching and working memory maintenance and updating, and we focus particularly on studies that are informative with respect to the question how positive affect and reward modulate complementary control modes (for reviews of the role of positive affect in other cognitive domains such as perception, attention, or problem-solving see Bolte & Goschke, 2010; Fredrickson, 2013; Friedman & Förster, 2010; Isen, 2007).

1.2. Conceptual and methodological issues

The term emotion has been notoriously difficult to define (Hamann, 2012; LeDoux, 2012) and it has even been asked how meaningful a categorical distinction between cognition and emotion (or "cognitive" and "affective" brain areas) is (Pessoa, 2008). In this article we use a pragmatic working definition, according to which emotions can be conceived as psycho-physiological response patterns which involve several components, including a (conscious or unconscious) evaluation of the significance of an event in the light of the organism's needs, motives, and goals; physiological responses of the autonomous nervous system as indicated by different indicators of increased arousal; the recruitment of brain circuits involved in the processing of reward, threat, or punishment; the generation of motivational tendencies that set particular categories of action into readiness (e.g., approach vs. avoidance); specific facial and postural expressions; and often (but not necessarily) a qualitative subjective experience (the feeling component) (Bolte & Goschke, 2010). The relation between emotion and motivation will be discussed in more detail in Section 3.3 on dissociations between positive affect and reward (see also Chiew & Braver, 2011).

In most studies reviewed in this article positive affect was induced by presenting positive emotional stimuli (e.g., pictures, movie clips) either on a trial-by-trial basis or before a block of trials, whereas a smaller number of studies examined effects of more enduring moods. Although phasic emotional responses and tonic moods likely differ with respect to underlying neural systems, the degree to which they capture focal attention, and whether they motivate emotion regulation strategies, to our knowledge no studies have systematically investigated how short-lived emotional responses to affective stimuli and tonic moods differ in their effects on cognitive control. As there is not sufficient evidence for a systematic comparison of effects of tonic and phasic emotions, we have organized our review along the control functions under investigation (set shifting; working memory maintenance and updating) rather than according to emotion induction methods.

2. An integrative theoretical framework: control dilemmas and complementary control modes

2.1. Control dilemmas

Our discussion of emotional modulations of cognitive control is guided by a theoretical framework that distinguishes different global control modes, which serve complementary adaptive functions in goal-directed action. While the evolution of cognitive control capacities dramatically increased the flexibility of human action, as is evident in our ability to select actions based on anticipated future goals, to rapidly reconfigure behavioral dispositions according to changing intentions and instructions, and to maintain goals in the face of competing habitual or impulsive responses, this increase in cognitive and behavioral flexibility also gave rise to new kinds of conflicts. We conceive of such conflicts as *control dilemmas* to express the idea that goal-directed action in a changing environment is a multiple constraint satisfaction problem that confronts agents with fundamental trade-offs between antagonistic adaptive requirements (Goschke, 2000, 2003, 2013; Goschke & Dreisbach, 2008; Gruber & Goschke, 2004; Kuhl & Goschke, 1994) (for related ideas see Cohen, McClure, & Yu, 2007; Cools, 2008). In this review we focus specifically on what we term the *shielding–shifting dilemma*. On the one hand, goal-directed action requires that goals (e.g., finishing a review paper) are maintained and shielded from distracting stimuli (e.g., music from a neighborhood party) or competing response tendencies (to go dancing rather than continue writing) (Gollwitzer & Bayer, 1999; Hofmann, Schmeichel, & Baddeley, 2012; Kuhl, 1985). On the other hand, however, agents must be able to update cognitive sets, disengage from a currently active goal, and flexibly reconfigure response dispositions to adapt to significant changes in the environment or internal state (for instance, when noticing unexpected noise in the basement while writing at night).

A core assumption of control dilemma theory is that different control modes are associated with complementary benefits and costs. While strong goal-shielding supports behavioral persistence and cognitive stability, it may incur a cost in terms of perseverative behavior and impaired adaptation to changing contexts or task demands. Conversely, while weak goal shielding facilitates flexible set switching, it increases distractibility and the risk of unstable behavior that is driven by every minor change in the environment. Evidence for complementary benefits and costs of goal shielding stems from studies of conflict-induced adjustments of cognitive control. These studies have shown that response conflicts in interference tasks (e.g., Stroop or flanker tasks) trigger the enhanced recruitment of cognitive control, as indicated by the finding that interference from distracting information or competing responses is reduced on trials immediately following a response conflict (e.g., Fischer, Dreisbach, & Goschke, 2008; Gratton, Coles, & Donchin, 1992; Kerns et al., 2004; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) (for a review see