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Research report

Color vision predicts processing modes of goal activation during action cascading

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ABSTRACT

One of the most important functions of cognitive control is action cascading: the ability to cope with multiple response options when confronted with various task goals. A recent study implicates a key role for dopamine (DA) in this process, suggesting higher D1 efficiency shifts the action cascading strategy toward a more serial processing mode, whereas higher D2 efficiency promotes a shift in the opposite direction by inducing a more parallel processing mode (Stock, Arning, Epplen, & Beste, 2014). Given that DA is found in high concentration in the retina and modulation of retinal DA release displays characteristics of D2-receptors (Peters, Schweibold, Przuntek, & Müller, 2000), color vision discrimination might serve as an index of D2 efficiency. We used color discrimination, assessed with the Lanthony Desaturated Panel D-15 test, to predict individual differences ($N = 85$) in a stop-change paradigm that provides a well-established measure of action cascading. In this task it is possible to calculate an individual slope value for each participant that estimates the degree of overlap in task goal activation. When the stopping process of a previous task goal has not finished at the time the change process toward a new task goal is initiated (parallel processing), the slope value becomes steeper. In case of less overlap (more serial processing), the slope value becomes flatter. As expected, participants showing better color vision were more prone to activate goals in a parallel manner as indicated by a steeper slope. Our findings suggest that color vision might represent a predictor of D2 efficiency and the predisposed processing mode of goal activation during action cascading.

1. Introduction

One of the most important functions of cognitive control is action cascading, that is the ability to cope with multiple response options when confronted with various task goals. In such a situation, successful action control would require efficient activation of and switching between different task goals in order to properly organize behavior. This can be achieved via distinct strategies that are thought to lie on a

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continuum; on the one end is a more serial processing mode in which the next task goal is activated only when the previous task goal has finished, and on the other end is a more parallel processing mode in which the next task goal is activated when the previous task goal is still active (Mückschel, Stock, & Beste, 2014; Verbruggen, Schneider, & Logan, 2008).

Neurobiological models of action selection indicate dopamine (DA) plays a key role in action cascading and individual differences in DA function might predict the preferred (i.e., serial *vs* parallel) action cascading strategy. One particularly prominent model is the dual-state theory, which proposes that different DA receptors in the prefrontal cortex (PFC) exert opposite effects on activity states and cognition (Durstewitz & Seamans, 2008). This model, which is supported by a wealth of behavioral and electrophysiological data, suggests the dynamics of PFC activity lie on a continuum ranging from (i) a D1-dominated state that inhibits spontaneous but enhances task-related neural firing, thereby favoring robust online maintenance of representations, to (ii) a D2-dominated state that facilitates spontaneous neural firing and shifting between activity patterns, thereby allowing fast switching between representations. The dual-state theory has been successfully applied to action cascading performance, supporting the idea that different DA receptors shift the action cascading strategy into different directions: individuals with a genetic predisposition toward higher D1 efficiency demonstrated a more serial, step-by-step processing mode, whereas higher D2 efficiency predicted a more parallel, overlapping processing mode (Stock, Arning, Epplen, & Beste, 2014). Taken together, these findings suggest an individual with higher D1 efficiency is predisposed to a more serial action cascading strategy due to a stable but potentially rigid PFC processing state, whereas an individual with higher D2 efficiency is predisposed to a more parallel strategy due to a flexible but interference-prone PFC state.

In the present study we investigated whether individual differences in DA function could indeed predict the processing mode of goal activation in action cascading, using color vision (CV) discrimination as an indirect but low-cost and non-invasive marker of DA function. The retina is rich in DA and dysregulated retinal DA function is associated with impaired CV (Brandies & Yehuda, 2008). This is illustrated by populations thought to suffer from dysregulated DA function and that demonstrate impaired CV, such as patients with Parkinson's disease (Büttner, Patzold, Kuhn, Müller, & Przuntek, 1994; Büttner et al., 1995; Kertegle et al., 2010; T. Müller, Kuhn, Büttner, & Przuntek, 1997; Oh et al., 2011; Pieri, Diederich, Raman, & Goetz, 2000; Price, Feldman, Adelberg, & Kayne, 1992), attention-deficit/hyperactivity disorder (Banaschewski et al., 2006; Kim et al., 2014; Roessner et al., 2008), Gilles de la Tourette syndrome (Melun, Morin, Muise, & DesRosiers, 2001), cocaine users (Desai, Roy, Roy, Brown, & Smelson, 1997; Hulka, Wagner, Preller, Jenni, & Quednow, 2013), and in normal aging populations (Jackson & Owsley, 2003; Melun et al., 2001). One study so far has demonstrated CV can predict DA-related cognitive performance. Specifically, CV in healthy young adults predicted individual differences in the cognitive control of response conflict, with better CV predicting reduced response conflict in an auditory Simon task (Colzato, Sellaro, Hulka, Quednow, & Hommel, 2014).

Although the exact nature of the link between CV and DA-related performance is unclear, the modulation of DA release in the retina displays characteristics of D2 receptors (Peters, Schweibold, Przuntek, & Müller, 2000), raising the possibility that CV can predict individual differences in performance related to D2 efficiency. Consistent with this idea, administration of D2-like receptor antagonists leads to impaired retinal function (Fornaro, Calabria, Corallo, & Picotti, 2002) as observed in schizophrenia (Shuwairi, Cronin-Golomb, McCarley, & O'Donnell, 2002). Additionally, cocaine treatment decreases D2 receptor function (Madhavan, Argilli, Bonci, & Whistler, 2013), leading to increased cocaine craving (Volkow et al., 2006) which in turn is associated with CV impairment (Roy, Roy, Smelson, Brown, & Weinberger, 1997; Roy, Smelson, & Roy, 1996). Although these findings may point toward a particular role of D2 receptors in CV, it should be acknowledged that D1 receptors likely also play a role (Brandies & Yehuda, 2008) and to date it has been difficult to disentangle the exact contributions of D1 and D2 receptors. However, the aforementioned study relating action cascading performance to gene polymorphisms indicated that D1 and D2 exert opposite effects on the processing mode of goal activation (Stock et al., 2014). Hence, the present study can provide further insight into the role of D1 and D2 receptors in CV by comparing the relationship between CV and action cascading to the previous findings on action cascading and gene polymorphisms. Specifically, assuming CV indeed indicates D2 function and given that increased D2 efficiency is associated with a more parallel processing mode in action cascading (Stock et al., 2014), we would expect individuals with better CV to demonstrate a more parallel action cascading strategy. In contrast, if CV were to primarily reflect D1 receptor function then we would expect better CV to predict a more serial strategy. Because previous studies indicate DA function might be particularly related to CV in the blue-yellow domain (Banaschewski et al., 2006; Colzato et al., 2014; Desai et al., 1997; Hulka et al., 2013; Melun et al., 2001; Roessner et al., 2008), we also investigated whether blue-yellow CV in particular predicts the action cascading strategy.

To assess action cascading performance we used the stop-change paradigm (Verbruggen et al., 2008), an established diagnostic measure of action cascading. In this task participants need to respond as fast as possible to a GO stimulus, but in some trials a STOP signal, presented after a variable delay, indicates the need to withhold this response. A subsequent CHANGE signal indicates the new response rule that must be used to respond to the GO stimulus. In this task it is possible to calculate an individual slope value for each participant that estimates the degree of overlap in activation of the STOP and CHANGE goal. When the STOP process has finished at the time the CHANGE process is initiated, the slope value becomes flat and indicates more serial processing. In contrast, when the STOP process has not yet finished at the time the CHANGE process is initiated, the slope value becomes steeper and indicates more parallel processing. In line with our expectations, we predicted participants with better CV to be prone to activating goals in a parallel manner and thus demonstrate a steeper slope.