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# Impulsive oculomotor action selection in Parkinson's disease

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ABSTRACT

The effects of Parkinson's disease (PD) on the dynamics of impulsive action selection and suppression have recently been studied using distributional analyses, but with mixed results, especially for selection. Furthermore, some authors have suggested that impulsivity, regarded as a personality trait, shares common features with behavioral tasks' measures. The current study was designed to clarify the impact of PD on impulsive action selection and suppression, and investigate the link between cognitive action control and self-reported impulsivity. We administered an oculomotor version of the Simon task to 32 patients with PD and 32 matched healthy controls (HC), and conducted distributional analyses in accordance with the activation-suppression model. Patients and HC also filled out the Barratt Impulsiveness Scale (BIS) questionnaire. Results showed that patients with PD were faster overall and exhibited a greater congruence effect than HC. They also displayed enhanced impulsive action selection. By contrast, the suppression of impulsive responses was similar across both groups. Furthermore, patients had higher impulsivity scores, which were correlated with higher impulsive action selection and higher suppression. Our study yielded two interesting findings. First, PD resulted in a higher number of fast errors. The activation-suppression model suggests that patients with PD are more susceptible to the impulsive action selection induced by the irrelevant stimulus dimension. Second, impulsive action selection and suppression were both associated with trait impulsivity, as measured by the BIS, indicating that these two aspects of impulsivity share common features.

## 1. Introduction

Efficient cognitive control is vital when a choice has to be made between strong response alternatives. One of the underlying functions of cognitive control, the online resolution of conflict situations, also known as *cognitive action control*, has been extensively studied. Experimental tasks that put the participants in a situation of conflict between two response alternatives typically show that conflict resolution has a cognitive cost. One of the most widely used conflict-inducing paradigms is the Simon task (Simon and Berbaum, 1990). In this task, participants have to press a button according to the color of a circle displayed on either the right- or left-hand side of a screen. In incongruent situations, the color of the stimulus and its display side activate opposite responses, while in congruent situations, both items of information trigger the same response. Simon task studies have repeatedly shown that incongruent situations lead to an increase in reaction times (RTs), reflecting the so-called *Simon effect* or *congruence effect*, and a decrease in accuracy (Hedge and Marsh, 1975; Simon, 1969; Simon and Berbaum, 1990; Van der Lubbe and Verleger, 2002; Wöstmann et al., 2013).

The congruence effect is usually explained by dual-route models, which posit that response activation can follow two parallel routes: an automatic one and a controlled one (Kornblum et al., 1990). According to this view, the automatic route favors the expression of overlearned actions, while the controlled route fosters intention-driven behavior. Thus, during conflict tasks, the irrelevant dimension of the stimulus triggers a fast response through the automatic route, while the relevant dimension triggers a slower, goal-directed response through the controlled route. Accordingly, in the congruent situation, the automatic and controlled routes both support the same response, leading to response facilitation. In the incongruent situation, however, the two routes activate contrasting motor programs, and the individual must be

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able to suppress the automatic response activated by the irrelevant information in favor of the goal-directed one.

A recent model of cognitive action control refined the dual-route hypothesis by distinguishing between the processes of response selection and suppression. The activation-suppression model suggests that a selective inhibition mechanism is set up to suppress the inappropriate activation elicited by the irrelevant stimulus dimension (Ridderinkhof, 2002). However, this selective inhibition takes time to build up. As a consequence, the inappropriate automatic activation is hard to suppress immediately after stimulus presentation. The fastest responses in the incongruent situation are therefore more error prone. This has been highlighted using conditional accuracy functions (CAFs), which display accuracy as a function of the RT distribution divided into bins. The fastest responses (those in the first bin) are thought to reflect automatic activation by the irrelevant dimension, with a higher number of fast errors in the incongruent situation indicating more impulsive action selection. As the selective inhibition of this impulsive action selection takes time to become effective, we can assume that the inappropriate activation is more efficiently suppressed when responses are slow. This assumption is supported by delta plots describing the congruence effect (incongruent RTs minus congruent RTs for correct responses) as a function of RT distribution. Simon task delta plots typically show a decrease in the congruence effect as RTs increase, and the slope between the last two bins is thought to reflect the strength of the selective inhibition process, with a steeper negative slope corresponding to stronger inhibition (see van den Wildenberg et al. (2010), for a review). The fast error rate in CAFs and the strength of the last slope in the delta plots are increasingly being used as parameters to assess impulsive action selection and suppression in both healthy and pathological populations (Castel et al., 2007; Juncos-Rabadán et al., 2008; Proctor et al., 2005; Van der Lubbe and Verleger, 2002; Wylie et al., 2009a).

Cognitive action control is mostly supported by a prefrontal-basal ganglia network (see Ridderinkhof et al. (2011), for a review). More specifically, the pre-supplementary motor area (pre-SMA), which is part of the supplementary motor complex, the inferior frontal cortex (IFC), and the subthalamic nucleus (STN) are all thought to play a major role in impulsive action selection and suppression. The STN is thought to share direct connections with the pre-SMA and the IFC, forming a network that supports conflict resolution (Aron et al., 2007; Majid et al., 2013; Mink, 1996). For instance, a study focusing on the effect of deep brain stimulation of the STN in patients with Parkinson's disease (PD) revealed that electrical stimulation of the STN results in more impulsive action selection and enhanced late selective inhibition (Wylie et al., 2010b). The role of the STN in inhibitory control has also been confirmed by direct recordings in patients with PD, which have revealed changes in activity relative to stopping performance in a stop signal task (Alegre et al., 2013), and by the study of PD patients who underwent subthalamotomy (Obeso et al., 2014).

Since cognitive action control relies on prefrontal-basal ganglia networks, we would expect diseases that affect these brain networks, such as PD, to hinder its efficiency. Most of the studies that have investigated cognitive action control so far have found that conflict resolution is indeed impaired in patients with PD, as indicated by a higher congruence effect (Brown et al., 1993; Praamstra et al., 1999, 1998; Praamstra and Plat, 2001; Schmiedt-Fehr et al., 2007; van Wouwe et al., 2014; Wylie et al., 2005), although some studies have failed to observe this effect (Cagigas et al., 2007; Falkenstein et al., 2006; Lee et al., 1999). This impairment has been shown to depend on dopaminergic treatment (van Wouwe et al., 2016) and disease characteristics such as motor symptom severity (Vandenbossche et al., 2012, 2011; Wylie et al., 2010a). However, very few studies have investigated the effect of PD on the dynamics of cognitive action control as proposed by the activation-suppression model. Most of these studies assessed PD patients with dopaminergic medication and their results are somewhat inconsistent. Although most of them describe impaired selective inhibition in patients, revealed by a less negative final delta-plot slope (van Wouwe et al., 2014; Wylie et al., 2010a, 2009a, 2009b), the effect of PD on impulsive response selection is unclear. For example, when Wylie et al. (2009a) used a flanker task to assess medicated patients with PD, they found that patients exhibited a greater congruence effect than HC, and stronger impulsive response selection, as revealed by a lower accuracy rate for the first CAF bin. In a subsequent study, however, they failed to demonstrate an increased congruence effect or increased susceptibility to response capture, except in patients with the most severe motor symptoms (Wylie et al., 2010a). The reasons for such mixed results are uncertain. It is possible that heterogeneity in the experimental methods might play a role. For example, Wylie et al. have used an Eriksen flanker task (2009) then a Simon task (2010) and observed different results. This could be explained by the nature of the stimuli, known to influence the strength of the conflict (Wascher et al., 1999; Mattler, 2003). It is also possible that heterogeneity in the patients' characteristics might have influenced the performance. For instance, Wylie et al. (2010a) showed that the severity of the motor symptoms had an impact on the amount of fast errors. Among the studies investigating the effect of PD on the dynamics of cognitive action control, only one assessed PD patients without dopaminergic medication (van Wouwe et al., 2016). This study revealed no difference between patients without medication and healthy controls in impulsive action selection. While this suggests that there is no pure PD effect on impulsive action selection, it remains unclear whether PD patients with their usual medication are impaired or not in this process. It therefore remains unclear whether patients with PD display greater impulsive action selection.

Patients with PD have been shown to be faster than HC in the oculomotor response modality, and oculomotor versions of the Simon task have been found to yield more errors than manual versions (Fielding et al., 2005; Sullivan and Edelman, 2009). We suggest that most errors in the oculomotor tasks are fast errors, as predicted by the activation-suppression model, and that oculomotor versions of the Simon task are more useful for gauging impulsive action selection. We therefore hypothesized that if patients with PD are characterized by greater impulsive action selection, an oculomotor version of the Simon task is more likely to bring it to light. We also chose to use the oculomotor modality as there is a great amount of studies on the impact of PD on saccades performances that may, in part, rely on impairment in cognitive action control. For example, PD usually impairs volitional saccades (slowing RT and decreasing accuracy, see Terao et al. (2013) for a review) while visually-guided saccades are relatively spared. Furthermore, investigating conflict effect on eye movements has an important implication regarding the ability to ignore irrelevant stimuli from the environment and favor relevant ones. This is of major interest in PD as these patients have been shown to be more attracted than controls by irrelevant visual stimuli (Deijen et al., 2006, van Stockum et al., 2011). The first objective of the current study was thus to confirm this effect of PD on cognitive action control using an oculomotor version of the Simon task that has yielded results consistent with the activation-suppression model in healthy controls (Duprez et al., 2016a). We hypothesized that if PD results in greater impulsive action selection, it would increase the number of fast errors in CAF.

Our second objective was to investigate the relationship between cognitive action control abilities and impulsivity, treated as a personality trait. More specifically, we wondered whether there is a link between impulsive action selection and suppression in conflict tasks such as the Simon task and self-reported impulsivity. Some studies have reported inconsistent results regarding the potential link between different measures of impulsivity (Aichert et al., 2012; Caswell et al., 2015). The activation-suppression model allows for the investigation of impulsive action selection and suppression, and we argued that this link appears when focusing on the first CAF bin or last delta-plot slope. We therefore sought to evaluate the link between self-reported