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Cognitive control outside of conscious awareness

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ABSTRACT

To test whether cognitive control can operate fully unconsciously on conflicts arising between two interfering subliminal stimuli, we designed a priming paradigm in which a subliminal reverse Color-Word Stroop item (a color word written on a congruent/incongruent color rectangle) preceded a supraliminal one in each trial. We found (a) a conflict adaptation effect, with a smaller reverse Stroop effect on the visible probe items after incongruent than after congruent subliminal prime items and (b) a negative priming effect, with longer reaction-times on incongruent visible probe items when the color word corresponded to the color of the rectangle in the preceding subliminal prime item than when it was not. These effects replicate the ones classically reported in studies using visible items and suggest that cognitive control was transferred from the subliminal prime to the visible probe items. Taken together, our results demonstrate that cognitive control can operate on conflicting subliminal information.

1. Introduction

In the past 20 years, a number of studies in the field of consciousness have provided evidence that emotional (e.g., Whalen et al., 2004), perceptual (e.g., Sterzer, Haynes, & Rees, 2016) and even decisional processes (Custers & Aarts, 2010) can operate outside of awareness. These findings questioned whether all processes can operate outside of consciousness (Dehaene, 2011, 2014; Lau, 2009), even those that have been traditionally considered key attributes of conscious experience such as cognitive control (Hommel, 2007). Cognitive control is defined as an ensemble of top-down control processes (i.e., executive functions) that allows the cognitive system to perform specific tasks in contexts in which relying on automatic processes is insufficient or impossible (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Diamond, 2013). Historically, consciousness and cognitive control have often been associated (Jack & Shallice, 2001; Jacoby, 1991), in part because cognitive control consistently elicits activation in the prefrontal cortex (Niendam et al., 2012) – a region deemed to be at the root of conscious experience (Dehaene & Naccache, 2001; Lau & Rosenthal, 2011; and see Rees, 2007 for a general review). Previous studies on cognitive control and consciousness have investigated whether response inhibition or interference control could operate outside of consciousness.

Studies have demonstrated that *response inhibition*, i.e., the ability to prevent a prepotent motor response irrelevant to an ongoing task, can be triggered by subliminal information in Go/No-go tasks (Chiu & Aron, 2014; van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; van Gaal, Ridderinkhof, Scholte, & Lamme, 2010; Wokke, van Gaal, Scholte, Ridderinkhof, & Lamme, 2011) and stop-signal tasks (van Gaal, Lamme, Fahrenfort, & Ridderinkhof, 2011; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009). For instance, in one subliminal go/no go study (van Gaal, Ridderinkhof, et al., 2010), participants were asked to respond to a

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Go probe stimulus (i.e., an annulus) only if it was preceded by a Go prime stimulus (i.e., a small diamond). If it was preceded by a No-go prime stimulus (i.e., a small square), the participants had to withhold their response. Half of these primes were visible, the other half were not. Importantly, the Go stimulus was always visible. The participants' responses were slowed down by the No-go prime stimuli even when the stimuli were presented subliminally, and this slowdown was correlated with functional activity in areas devoted to response inhibition (i.e., pre-supplementary motor area, inferior frontal cortex and anterior insula).

Converging evidence for unconscious cognitive control has also been reported on interference control tasks. *Interference control* is a set of processes that enable us to selectively attend to goal-relevant information by suppressing attention to (and processing of) other stimuli (Diamond, 2013). Interference control is generally studied using interference tasks. Interference tasks consist of situations in which task-relevant information (a stimulus or stimulus feature) leads to a different response than task-irrelevant information presented simultaneously or nearly simultaneously, generating a response conflict resulting in longer reaction times (RTs) and/or higher error rates (ERs) compared to RTs and ERs in a control condition with no response conflict. In the Color-Word Stroop task for example (Stroop, 1935), participants are asked to determine the ink color (i.e., the task-relevant information) of printed words that denote colors (i.e., the task-irrelevant information). When the ink color and the color denoted by the word are incongruent (i.e., incongruent items), participants require more time and commit more errors than when the color and word are congruent (i.e., congruent items), leading to a so-called Stroop or congruency effect. Two additional effects have been reported in interference tasks and the Color-Word Stroop task in particular: the negative priming effect (e.g., Tipper, 1985) and the conflict adaptation effect (or *Gratton effect* [Gratton, Coles, & Donchin, 1992]). Indeed, participants require more time to identify the ink color on an incongruent item if it is the same as the color denoted by the word in the preceding incongruent item than if it is not (i.e., the negative priming effect, Dalrymple-Alford & Budayr, 1966; Fox, 1995; Pritchard & Neumann, 2004; Tipper, Bourque, Anderson, & Brehaut, 1989). In addition, the Stroop effect (i.e., difference in RTs and/or ERs between incongruent and congruent items) is smaller after incongruent items than after congruent items. Conflict adaptation is thought to reflect the ability to adjust information processing and behavior after experiencing a conflict (Desender & Van den Bussche, 2012; Kunde, Reuss, & Kiesel, 2012).

Behavioral and neuroimaging studies made use of the conflict adaptation effect to determine whether interference control can be triggered by subliminal information (Ansorge, Fuchs, Khalid, & Kunde, 2011; Boy, Husain, & Sumner, 2010; Desender, Van Lierde, & Van den Bussche, 2013; Francken, van Gaal, & de Lange, 2011; Frings & Wentura, 2008; Greenwald, Draine, & Abrams, 1996; Jiang, Zhang, & van Gaal, 2015a, 2015b; Merikle & Joordens, 1997; van Gaal, Lamme, & Ridderinkhof, 2010). In all of these studies, a subliminal prime is presented before a *visible* probe. The subliminal prime information could be either congruent (i.e., congruent trial) or incongruent (i.e., incongruent trial) with the information to process on the probe. For instance, in a study by van Gaal, Lamme, et al. (2010), participants were asked to determine the direction (left or right) of visible arrows (i.e., probes) preceded by subliminal arrows (i.e., primes) pointing either to the same (in the congruent trials) or to the opposite (in the incongruent trials) direction as the probe. The rationale of this study and more generally of the studies of a similar topic of research is as follows: if interference control can operate outside of consciousness, then consistent with the conflict adaptation effect reported in interference control tasks, the congruency effect (here the difference in performance between incongruent and congruent trials) should be smaller after incongruent than after congruent trials. Number of studies have reported such conflict adaptation effect with a subliminal prime, suggesting that interference control can be triggered by subliminal information (Boy et al., 2010; Desender et al., 2013; Francken et al., 2011; Jiang et al., 2015a, 2015b; van Gaal, Lamme, et al., 2010). For instance, in the van Gaal, Lamme, et al. (2010) study, the participants not only required more time to determine the direction of the visible arrows in incongruent than in congruent trials but this congruency effect was also reduced after incongruent than congruent trials (i.e., a typical conflict adaptation effect). Note, however, that some studies failed to report conflict adaptation effects using similar paradigms (Ansorge et al., 2011; Greenwald et al., 1996).

All in all, a growing number of behavioral and neuroimaging studies suggest that cognitive control can operate unconsciously (Boy et al., 2010; Chiu & Aron, 2014; Desender et al., 2013; Francken et al., 2011; Greenwald et al., 1996; Jiang et al., 2015a; van Gaal et al., 2011, 2008, 2009; van Gaal, Ridderinkhof, et al., 2010; Wokke et al., 2011). However, all of these previous studies focus on unconsciously *triggered* cognitive control, using either *response inhibition* paradigms in which the underlying executive processes are *triggered* by a subliminal cue but operate on a supraliminal stimulus presented subsequently or *interference control* paradigms in which an unconscious prime interferes – positively or negatively – with the processing of a following but *visible* probe. In both literatures, the subliminal conflict is systematically induced by a mismatch between the subliminal information conveyed by the prime and the supraliminal information conveyed by the probe. For instance the subliminal conflict is induced by the subliminal presentation of an arrow on the prime that points in the opposite direction as the visible arrow presented on the probe (van Gaal, Lamme, et al., 2010). Even stop-signal paradigms, in which a subliminal stop signal slows down the motor response associated with a previous visible stimulus, cannot rule out the possibility that executive control processes can only be implemented in situations where at least some piece of information causing the conflict is conscious. Thus, no study to date has provided evidence that cognitive control can operate in a context in which both the task-irrelevant information and the task-relevant information are not consciously perceived.

In the present study, we aimed to provide such evidence by designing a subliminal priming paradigm based on a classical interference control task, i.e., the reverse Color-Word Stroop task (Appelbaum, Boehler, Davis, Won, & Woldorff, 2014; Atkinson, Drysdale, & Fulham, 2003; Durgin, 2000; MacLeod, 1991). In this task, participants must determine the color denoted by a word (i.e., the task-relevant information) printed on a solid colored rectangle (i.e., the task-irrelevant information). As in the classical Color-Word Stroop task, RTs are typically slower and ERs are higher on incongruent items in which the color denoted by the word is incongruent with the color of the solid rectangle (e.g., BLUE written on a yellow rectangle) than on congruent items in which the two colors are congruent (e.g., BLUE written on a blue rectangle).

Each trial consisted of a subliminal prime item followed by a visible probe item. Both the prime and probe items were classical congruent or incongruent reverse Color-Word Stroop items. In our paradigm, the conflict occurred within the subliminal prime when