

# Anterior cingulate and prefrontal cortex activity in an FMRI study of trial-to-trial adjustments on the Simon task

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People alter their task performance on a trial-to-trial basis, for example after an incongruent trial on tasks involving response conflict. Previous research has found that these adjustments are most robust in the Simon task. One explanation for behavioral adjustments is the conflict-monitoring hypothesis, which posits that the dorsal anterior cingulate cortex (ACC) responds to conflict and that this serves as a signal to recruit other brain regions such as the prefrontal cortex (PFC) to minimize conflict and improve performance. However, another independently supported explanation for behavioral adjustments on the Simon task is the feature integration view, which can account for behavioral adjustments as the result of stimulus repetitions and alternations. Hence, by itself, evidence for behavioral adjustments on the Simon task does not clearly provide evidence for the conflict-monitoring hypothesis. However, the conflict-monitoring hypothesis does predict that behavioral adjustments on the Simon task should involve ACC conflict activity and PFC post-conflict activity. In the current study, consistent with the conflict-monitoring hypothesis, behavioral adjustments in performance on the Simon task were predicted by ACC conflict-related activity. In addition, subsequent behavioral adjustments were associated with PFC activity, with previous trial ACC conflict-related activity predicting greater PFC activity on subsequent trials. These results provide additional evidence that behavioral adjustments on the Simon task are due in part to ACC conflict monitoring and the subsequent recruitment of PFC to minimize conflict.

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## Introduction

People adjust their ongoing performance on behavioral tasks in a number of ways, such as slowing down and being more accurate after errors (Rabbitt, 1966; Laming, 1979). In addition, on tasks

involving response conflict (i.e., the simultaneous activation of at least two different responses), after incongruent high conflict trials participants also adjust their performance (Gratton et al., 1992). For example, a response conflict task such as the Stroop color naming task can involve high conflict incongruent trials (i.e., the word RED in green ink, correct response is green) and low conflict congruent trials (i.e., the word GREEN in green ink). After a high conflict incongruent trial, responses are slower for a subsequent congruent trial and faster for a subsequent incongruent trial. Specifically, on congruent trials responses are slower if preceded by an incongruent trial (i.e., iC trials) than if preceded by a congruent trial (i.e., cC trials). Moreover, participants are faster if an incongruent trial was preceded by an incongruent trial (i.e., ii trials) than if preceded by a congruent trial (i.e., ci trials). Hence, after conflict participants adjust their performance, responding slower for a subsequent congruent trial and faster for a subsequent incongruent trial.

One explanation for these post-conflict adjustments is the conflict-monitoring hypothesis (Botvinick et al., 2001, 2004). This hypothesis posits that at least two brain regions play distinct and complementary roles in behavioral adjustments. This hypothesis states that the dorsal anterior cingulate cortex (ACC) is activated by the occurrence of response conflict (Carter et al., 1998; Botvinick et al., 1999). The monitoring of response conflict by the ACC then serves as a signal that results in the recruitment of other brain regions to minimize the amount of conflict on subsequent performance (Botvinick et al., 2001; Cohen et al., 2000; Kerns et al., 2004). The prefrontal cortex (PFC) is one brain region thought to be engaged after the occurrence of conflict to subsequently minimize conflict (by providing a contextually or task-set appropriate biasing signal to poster regions; Botvinick et al., 2001; Miller and Cohen, 2001). Hence, from the conflict-monitoring view, ACC conflict monitoring serves as a signal that results in the recruitment of PFC to minimize subsequent conflict and improve performance.

However, in addition to the conflict-monitoring hypothesis, there are other explanations for post-conflict behavioral adjustments, such as the feature integration view. From this perspective, behavioral adjustments are the result of exact stimulus repetitions and alternations (Hommel et al., 2004). For example, consider the

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Simon task (Simon and Small, 1969; Lu and Proctor, 1995) on which two stimulus dimensions can vary from trial to trial: stimulus location (e.g., right or left) and stimulus identity (e.g., red or green object, necessitating either a right or left response, respectively). On the Simon task, only cC and iI trials involve exact stimulus repetitions (e.g., a green object on the left on two consecutive trials). Given that the post-conflict adjustment effect involves cC trials being faster than iC trials and iI trials being faster than cI trials, then faster responses on exact stimulus repetitions for only cC and iI trials can account for some evidence of post-conflict behavioral adjustments (Mayr et al., 2003). But in addition, on all other cC and iI trials not involving an exact stimulus repetition, they involve an exact stimulus alternation (e.g., green on left followed by red on right). It has been argued that people process perceptual stimuli as integrated event files (integration of both stimulus and response features, i.e., as object on left necessitating a right-hand response; Hommel et al., 2001; Stoet and Hommel, 1999). If both stimulus dimensions change, this complete alternation can be used to indicate a faster response. However, when only one stimulus dimension changes (i.e., red but still on left), RT has been found to increase because of the partial match to the previous trial. Hence, from this feature integration view, behavioral adjustments on the Simon task can be accounted for by cC and iI trials always involving either exact stimulus repetitions or alternations (thereby decreasing RT) whereas iC and cI trials always involve a partial match with the previous trial's stimuli (thereby increasing RT). Importantly, evidence for the feature integration view has been found in situations without response conflict (Hommel et al., 2004). This suggests that evidence of behavioral adjustments on some response conflict tasks may not necessarily indicate conflict monitoring.

Some research that does support a role for conflict monitoring in behavioral adjustments comes from brain imaging. The conflict-monitoring hypothesis predicts that ACC conflict-related activity should predict adjustments in performance. Moreover, it predicts that during post-conflict adjustment trials that PFC should be active. Consistent with this, in a study using the Stroop task, it was found that ACC conflict activity predicted greater post-conflict adjustments (Kerns et al., 2004). At the same time, greater subsequent post-conflict adjustments were associated with greater PFC activity. Hence, on the Stroop task, it appears that conflict monitoring may play a role in behavioral adjustments.

However, it is unclear whether these results for the Stroop task would also be found on other response conflict tasks. In fact, there is some evidence from previous research that the size of trial-to-trial adjustments might vary across response conflict tasks. For example, some studies have not reported significant trial-to-trial adjustments in the Eriksen flanker task after the removal of stimulus repetitions (Mayr et al., 2003; Nieuwenhuis et al., *in press*). On the Stroop task, conflict adjustments have been reported without stimulus repetitions in at least three studies (Egner and Hirsch, 2005a; Kerns et al., 2004, 2005), although in two of these studies the overall effect was of only moderate to large size and was not always consistent across both current trial types (e.g., only iI differed from cI or only iC differed from cC; Kerns et al., 2004, 2005). In contrast, the response conflict task, which seems to consistently produce the largest conflict adjustment effect sizes, is the Simon task (Sturmer et al., 2002; and even without exact stimulus repetitions, Sohn and Carter, 2006). On the surface, this seems counterintuitive because the Simon task involves a smaller behavioral RT interference effect (i.e., incongruent RT minus

congruent RT) than either the Eriksen or the Stroop tasks (e.g., in a recent behavioral study with  $n > 300$ , interference effects for the Simon, Eriksen, and Stroop tasks were 26.9, 69.2, and 183.7 ms, respectively; Kerns, 2006).

In part, one explanation for the variation in the size of post-conflict adjustment effects across tasks is the extent, consistent with the feature integration view (Hommel et al., 2004), to which iC and cI trials involve a partial match to the previous trial's stimuli. On the Simon task, with two possible relevant and irrelevant stimuli, all iC and cI trials involve a partial match, which can account for a large adjustment effect. In contrast, the Stroop task usually involves more than two possible relevant and irrelevant stimuli, with some iC and cI trials involving exact stimulus alternations (Kerns et al., 2004), which can account for the reduced size of the adjustment effect. In support of this, the one imaging Stroop study that found the largest post-conflict adjustment effect involved only two possible relevant and irrelevant stimuli and therefore involved all partial matches on iC and cI trials (Egner and Hirsch, 2005a).

Given evidence for the effect of stimulus repetitions and alternations on behavioral adjustment, this leaves open the possibility that behavioral adjustments on the Simon task may not be due to conflict monitoring. If true, this would suggest that the conflict-monitoring hypothesis may not apply to all response conflict tasks, which might suggest important limits on the theory. The current study examined whether conflict adjustments occurred on the Simon task and whether they were associated with ACC and PFC activity. According to the conflict-monitoring hypothesis, although repetitions and alternations should influence performance (Cho et al., 2002; Hommel et al., 2004), a previous trial's ACC conflict activity should still predict the subsequent occurrence of behavioral adjustments (Jones et al., 2002). Moreover, trials involving large behavioral adjustments (i.e., both speeding up on iI trials and slowing down on iC trials) should be associated with PFC activity, which should be associated with amount of ACC activity on the previous trial.

## Materials and methods

### Participants

Twenty-six right-handed individuals (14 females) with an average age of 24.2 years ( $SD = 4.5$ , range 18–36) participated in this study and were paid \$30 for their participation.

### Behavioral task

In the scanner, participants performed the Simon task (Lu and Proctor, 1995; Simon and Small, 1969). On each trial, participants saw a circle in either red or green ink on the left or right side of their visual field. Participants needed to respond with their right index finger for green circles and with their left index finger for red circles. Each trial began with a fixation cross presented for 250 ms. Then a green or red circle appeared for 1500 ms, followed by a blank screen for 750 ms (given an average reaction time of less than 700 ms, following Wuhr and Ansorge, 2005, the average response to stimulus interval was a little more than 1800 ms). Participants completed 8 blocks of 40 trials each. Each trial was either a congruent or an incongruent trial. On congruent trials, the location of the stimulus matched the side of response (e.g., a green circle, necessitating a right-hand response, presented on the right

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