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Evidence for trial-by-trial dynamic adjustment of task control in unmedicated adults with OCD

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ABSTRACT

According to the conflict monitoring theory, executive control requires two separable processes: conflict-monitoring and conflict-resolution. Deficits in executive control have been observed in adults with obsessive-compulsive disorder (OCD). However, it is not yet clear whether these deficits can be attributed to deficits in conflict-monitoring, in conflict-resolution, or in both. We examined this question by administrating the Simon task to 67 unmedicated adults with OCD and 67 matched controls. The interference effect (incongruent minus congruent) was used to measure conflict-resolution. Trial-by-trial dynamic adaptation (i.e., the Gratton effect), which is indicated by smaller interference effect after conflict-laden trials compared to after non-conflict-laden trials, was used to measure conflict-monitoring. A similar interference effect was found in both the OCD and HC groups with no significant between group differences. Following incongruent trials, the interference effect became smaller for the control group as expected, but was completely eliminated for the OCD group. These data add to the accumulating evidence indicating that conflict-resolution is not globally deficient in unmedicated OCD patients and provide direct evidence that conflict-monitoring is heightened in OCD patients. Our results challenge the assumption of cognitive inflexibility in OCD and highlight the importance of studying unmedicated subjects when investigating executive control.

In everyday life we often face the need to allocate cognitive efforts to guide behavior in accordance with internal goals. These efforts are governed by *executive control* — a core cognitive function that allows us to achieve and maintain goal directed behavior (Banich, 2009; Miyake et al., 2000). According to conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 1999), executive control consists of two processes: conflict monitoring, which relies in part on the anterior cingulate cortex (ACC) and registers the need for executive control; and conflict resolution, which involves various processes (including inhibition, working memory, and task-shifting) and is supported by different areas of the pre-frontal cortex (PFC). Evidence suggests that obsessive-compulsive behaviors are associated with broad deficits in executive control (e.g., Snyder, Kaiser, Warren, & Heller, 2015). However, reported effect sizes tend to be modest and results have been inconsistent, with some studies finding intact executive control in OCD (Abramovitch, Abramowitzc, & Mittelman, 2013). In addition, it is not yet clear whether deficits in executive control are underlie by deficits in conflict resolution, conflict monitoring, or both. In the current study we aimed to examine this premise in a sample of 67 unmedicated OCD patients and 67 matched controls.

There are different ways to measure conflict resolution and conflict monitoring behaviorally, but one of the most common is to use neurobehavioral tasks (e.g., Stroop, Flanker, Simon tasks) that introduce conflict and measure the ability of subjects to resolve this conflict *and* make conflict-related adjustments. For example, interference (reaction time (RT) for incongruent trials – RT for neutral trials) on the Stroop task (MacLeod, 1991; Stroop, 1935) is reduced on blocks with high proportion of conflict-laden trials and increased on blocks with low proportion of conflict-laden trials (e.g., Kalanthroff, Davelaar, Henik, Goldfarb, & Usher, 2018; Tzelgov et al., 1992). That interference is reduced on trials that follow conflict-laden trials is known as the post-conflict adaptation or the Gratton effect (e.g., Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Gratton; Coles, & Donchin, 1992; Ullsperger, Bylsma, & Botvinick, 2005). These effects have been interpreted to suggest that an encounter with a conflict activates the conflict monitoring system and thus leads to more efficient conflict detection.

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Prior studies suggest altered conflict monitoring in OCD patients. Kalanthroff and colleagues administered two block of the Stroop task that differ in the proportion of conflict-laden trials to OCD patients and healthy control (HCs). Replicating previous findings, HCs exhibited larger interference effect (indicating less efficient conflict resolution) in the low compared to the high conflict-laden proportion block. However, in OCD patients the interference effect was comparable in both blocks, so that in low conflict-laden blocks, OCD patients displayed a smaller interference effect (indicating more efficient conflict resolution) compared to HCs (Kalanthroff, Anholt, & Henik, 2014; for similar results using the Flanker task see:; Soref, Dar, Argov, & Meiran, 2008). This finding indicates more efficient conflict monitoring in OCD on blocks that commonly reduce the efficiency of conflict monitoring (i.e., low conflict-laden proportion). Furthermore, using behavioral and electrophysiological measures, Endrass, Klawohn, Schuster, Kathmann (2008) found a higher ERN-amplitude and a more pronounced reduction of the interference effect following incongruent trials (i.e., a larger Gratton effect) in patients with OCD compared to HCs. Finally, an fMRI study assessed brain activity as a function of congruency on current and previous trials of the Simon task and found that after a conflict-laden trial, OCD patients activated fronto-striatal regions (putamen, insula, and inferior frontal gyrus) more than HCs (Marsh et al., 2014). Together, these findings suggest abnormally heightened conflict monitoring in patients with OCD. These findings are consistent with the suggestions that the executive control system of individuals with OCD is hyperactive, trying to constantly account for external and internal "threats" (Abramovitch, Dar, Schweiger, & Hermesh, 2011), but contradicts the opposing view that executive control in OCD patients is reduced (e.g., Snyder et al., 2015) and inflexible (Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006).

To address this controversy in the literature, we used the Simon task to investigate both the conflict resolution and the conflict monitoring systems in a large sample of unmedicated OCD patients and matched controls. The Simon task is a classic executive control task which has been used widely to investigate both conflict resolution and conflict monitoring (Berger, Fischer, & Dreisbach, 2019; Craft & Simon, 1970; Marsh et al., 2014). Trial-by-trial sequential analyses of RT data as a function of congruency on the current and previous trials were used to measure and compare conflict resolution and conflict monitoring (respectively) across groups. Based on reported broad deficits in executive control (e.g., Snyder et al., 2015), we hypothesized that OCD patients compared to healthy volunteers would exhibit deficient conflict resolution as measured by larger interference effects on the current trial (i.e., incongruent RT minus congruent RT). Based on the literature reviewed above, we hypothesized that those with OCD compared to healthy volunteers would also exhibit heightened conflict monitoring (i.e., a larger Gratton effect as measured by smaller interference effects on trials that follow conflict-laden trials).

1. Method

1.1. Participants

Sixty-seven unmedicated adults with OCD and sixty-seven HC participants were recruited through flyers, internet advertisements, and word-of mouth.[1] The groups were matched by age, sex, ethno-racial, and IQ (Table 1). Participants were right-handed, had no history of neurological illness, past seizures, head trauma with loss of consciousness, mental retardation, pervasive developmental disorder, or current Axis I disorders (other than OCD for the OCD participants). All participants were free of psychotropic medications. Eleven OCD patients had a lifetime history of a depressive episode. Seven participants (3 HCs and 4 OCD) were excluded from further analyses due to low accuracy rates on the Simon task (< 75%). Demographics and clinical characteristics of the analyzed sample of 63 OCD patients and 64 HCs are presented in Table 1. A power analysis using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007), indicated that the current sample allowed for examination of the within-between interaction at a power > 99% to test small-medium size with a Type I error ($\alpha < 0.05$). The study was approved by the Institutional Review Board of the New York State Psychiatric Institute at Columbia University Medical Center. Participants provided written informed consent.

Table 1
Demographics and clinical characteristics.

	Healthy Control (N = 64)		OCD(N = 63)		*p-value**
Demographics					
Age (years; mean, SD)	29.08	(7.85)	28.87	(7.18)	.88
Education (years; mean, SD)	15.50	(2.29)	15.42	(1.53)	.89
WASI IQ Score (mean, SD)	109.09	(13.68)	110.96	(14.22)	.93
Sex (n, % female)	31	(48%)	31	(49%)	.93
Ethnicity (n, % Hispanic)	8	(13%)	6	(10%)	.59
Race					.96
Asian/Pacific Islander (n, %)	9	(14%)	8	(13%)	
African-American (n, %)	11	(17%)	9	(14%)	
Caucasian (n, %)	40	(63%)	42	(67%)	
Other/Missing	4	(6%)	4	(6%)	
Clinical Characteristics					
Y-BOCS Total (mean, SD)	0.21	(1.12)	24.76	(3.50)	
Obsessions (mean, SD)	0.08	(0.45)	11.95	(1.91)	
Compulsions (mean, SD)	0.13	(0.77)	12.81	(2.19)	
Age of OCD Onset, yrs (mean, SD)	–	–	15.52	(6.24)	
Duration of Illness, yrs (mean, SD)	–	–	13.35	(9.36)	
HAM-D Scores (mean, SD)	0.62	(1.05)	6.10	(4.55)	
Target Symptoms					
Symmetry/ordering (n, %)	23	(37%)	–	–	
Doubt/checking (n, %)	55	(87%)	–	–	
Contamination/cleaning (n, %)	32	(51%)	–	–	
Taboo thoughts (n, %)	22	(35%)	–	–	
Hoarding (n, %)	1	(2%)	–	–	

HAM-D = Hamilton Depression Scale; OCD = obsessive-compulsive disorder; WASI = Wechsler Abbreviated Scale of Intelligence; Y-BOCS = Yale-Brown Obsessive Compulsive Scale. SD = standard deviation. * p-value for t-test (Age, Years of Education, WASI IQ Score) and Pearson χ^2 (sex, ethnicity, race) for any group differences. As can be seen, none of the between-groups differences are significant.

1.2. Clinical evaluation

Formal diagnoses of OCD and the presence of comorbid diagnoses were established by a psychiatric evaluation (conducted by a licensed psychiatrist who did not have other contact with the participant). On the day of the experiment, a trained rater (PhD or MD) who had no other contact with the participants confirmed the diagnosis with the Structured Clinical Interview for DSM-IV (First, Spitzer, Gibbon, & Williams, 2002), and assessed OCD severity with the Yale-Brown Obsessive Compulsive Scale (Y-BOCS; Goodman et al., 1989), depressive severity with the Hamilton Depression Scale (Hamilton, 1967), and full-scale IQ with the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1981). Both raters received monthly reliability training and supervision and were blind to the study design and goals.

1.3. Simon task

Stimuli presentation was control by E-Prime-2 software (Psychology Software Tools, Inc., Sharpsburg, Pennsylvania). On each trial,

[1] 16 out of 67 OCD patients (and no HC) also participated in Marsh et al. (2014) which focused on brain activity during performance on the Simon task.

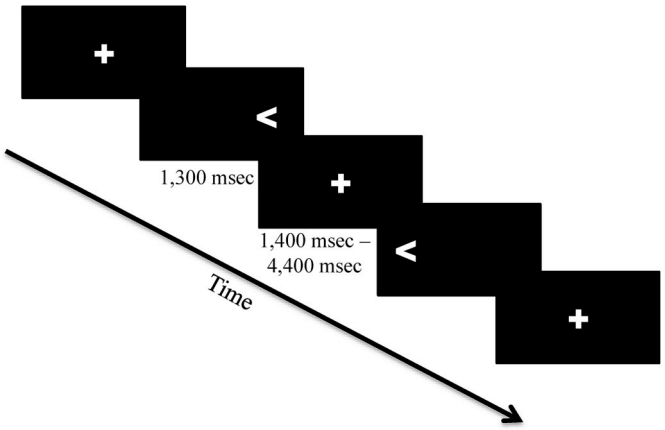

Fig. 1. Experimental procedure. Example of an incongruent trial followed by a congruent trial.

participants were asked to respond to a white arrow (against a black background) pointing left or right, which appeared to the left or right of a white fixation at midline (see Fig. 1). Stimuli subtended 1 vertical and 3.92 horizontal degrees of the visual field. Stimuli were "congruent" (pointing in the same direction as their position on the screen; e.g., "→" on the right side of the screen), "incongruent" (pointing opposite their position on the screen; e.g., "→" on the left side of the screen), or "blank" (no target). Participants were instructed to respond quickly to the direction of the arrow by pressing a button on a response box, with the index finger of their right hand for a left-pointing arrow and the middle finger of that hand for a right-pointing arrow. The Stimulus duration was 1300 ms, with a jittered interval between trials (range: 1400 ms–4400 ms). Each run contained 55 stimuli, with 22 congruent stimuli, 22 incongruent stimuli. These stimuli were arranged and presented in a pseudorandom order. Each experiment contained 3 runs, totaling 66 congruent and 66 incongruent stimuli.

1.4. Statistical methods

The data that support the findings of this study are openly available at http://www.kalanthroff.com/data/dynamic_adjustment_in_ocd.xls. Independent *t*-tests and Pearson χ^2 were used to assess group differences in demographic characteristics. To analyze performance on the Simon task, RT and accuracy data were subjected to two-way analyses of variance (ANOVA) with Group (OCD vs. HC) as a between-subjects factor and Congruency (congruent vs. incongruent) as a within-subjects factor. To test the sequential effect of the previous trial(N-1) congruency, RT data was subjected to a three-way ANOVA with Group as a between-subjects factor, Congruency(N; on the current trial), and Congruency(N-1; on the previous trial) as within-subject factors. Planned comparisons were conducted via separate t-tests to investigate the congruency effect (incongruent vs. congruent) for each group in each Congruency(N-1) condition.

2. Results

N trial (To assess Conflict Resolution). Mean RT and % accuracy on N trials are shown by Group in Table 2. No significant Group × Congruency interactions on RT or accuracy were detected, such that the interference effect (incongruent RT-congruent RT) was similar across the OCD and HC groups (**RT:** $F(1, 125) = 0.45$, $MSE = 1051.96$, $p = .50$; **Accuracy:** $F(1, 125) = 0.25$, $MSE < 0.01$, $p = .62$; see Fig. 2 top). No main effects of Group on RT or accuracy were detected (**RT:** $F(1, 125) = 2.22$, $MSE = 17{,}168.51$, $p = .14$; **Accuracy:** $F(1, 125) = 1.67$, $MSE = 0.01$, $p = .20$). There was a significant main effect for Congruency (**RT:** $F(1, 125) = 137.04$, $MSE = 1051.96$, $p < .001$, $\eta^2 = 0.52$; **Accuracy:** $F(1, 125) = 23.27$, $MSE < 0.01$, $p < .001$, $\eta^2 = 0.16$, with slower RTs and lower accuracy for incongruent trials compared to congruent trials in both groups (Table 2).

Table 2
Results.

		OCD (N = 63)			HC (N = 64)		
		RT	SE	ACC	RT	SE	ACC
N Trial							
Congruent		583	12	.96	555	12	.98
Incongruent		628	11	.94	606	12	.96
Interference		*45**	*6*		*51**	*5*	
N-1 Congruent							
Congruent	564	12	.97	539	12	.97	
Incongruent	639	12	.95	610	13	.96	
Interference	*75**	*7*		*71**	*6*		
N-1 Incongruent							
Congruent	601	13	.97	571	12	.98	
Incongruent	613	12	.96	600	13	.96	
Interference	*12*	*7*		*29**	*7*		

Reaction time (*RT in ms*), standard error of the mean (SE) of the difference, and accuracy (*ACC*) of the different congruency conditions (top) and as a function of N-1 congruency in the two groups. Interference = Incongruent – Congruent * - $p < 0.001$.

N-1 trial (To assess Conflict Monitoring). For the N-1 sequential analyses (see Table 2), there was a significant three-way interaction between Congruency(N), Congruency(N-1), and Group ($F(1, 125) = 5.01$, $MSE = 722.69$, $p = .03$, $\eta^2 = 0.04$; see Fig. 2 bottom) and a significant Congruency(N) X Congruency(N-1) two-way interaction ($F(1, 125) = 118.38$, $MSE = 722.69$, $p < .001$, $\eta^2 = 0.49$). As can be seen in Fig. 2 (bottom) and in Table 2, the interference effect following congruent trials was significant and comparable for both groups (**HC**: $t(64) = 11.73$, $p < .001$, Cohen's $d = 1.46$; **OCD**: $t(62) = 10.09$, $p < .001$, Cohen's $d = 1.27$). Following incongruent trials, the interference effect became smaller (RTs on congruent trials became slower while RTs on incongruent trials become faster; Fig. 2 and Table 2) for both groups. However, while the interference effect was still significant for the HC group ($t(64) = 4.39$, $p > .001$, Cohen's $d = 0.55$), it was not for OCD participants ($t(62) = 1.73$, $p = .10$, Cohen's $d = 0.21$). This difference was significant ($t(125) = 1.75$, $p = .04$, Cohen's $d = 0.31$.

3. Discussion

We administered the Simon task and analyzed the interference effect and trial-by-trial post-conflict dynamic adaptation (i.e., the Gratton effect) to examine conflict resolution and conflict monitoring in a large sample of unmedicated OCD patients and HCs. The interference effect was comparable across groups indicating no significant differences in conflict resolution between OCD patients and HCs. However, there was a difference in trial-by-trial post-conflict adaptation: in both groups, the interference effect was similar following congruent trials, and smaller after incongruent trials compared to after congruent trials. Interestingly, while the interference effect was no longer observed in the OCD group following incongruent trials, it was still significant for the HC group. In other words, OCD patients exhibited a larger post-conflict adaptation Gratton effect compared to HCs, indicating heightened conflict monitoring in OCD patients.

Findings from prior studies using various tasks of executive control processes suggest that OCD is characterized by deficient executive control (e.g., Kuelz, Hohagen, & Voderholzer, 2004; Penades, Catalan, Andres, Salamero, & Gasto, 2005; Snyder et al., 2015). At the same time, these findings are characterized by inconsistencies, failed

[2] Note: The Wisconsin card sorting task is likely to increase uncertainty (when sorting rule changes) especially for OCD patients, creating a potential confound.

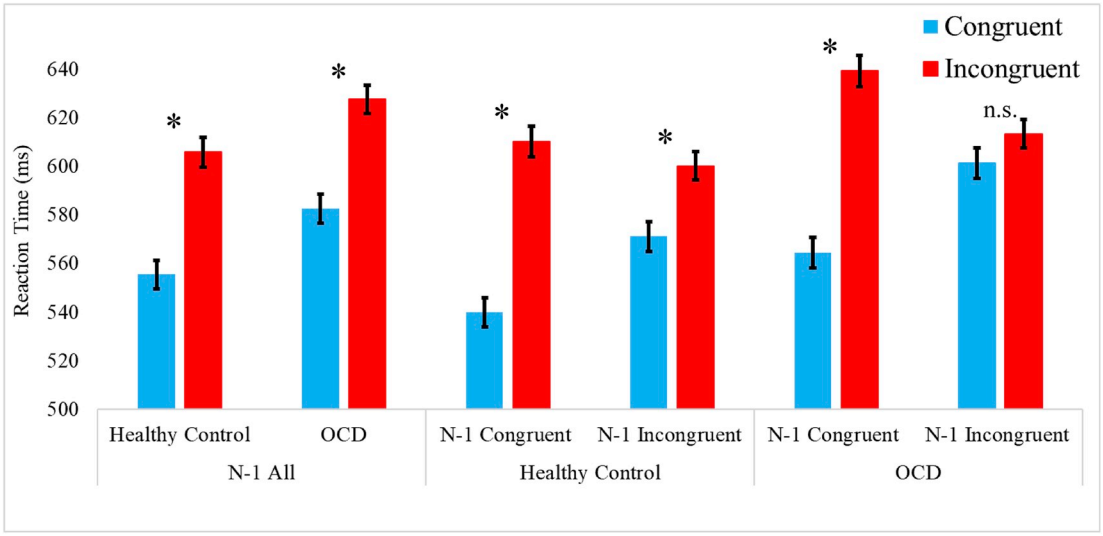

Fig. 2. Mean reaction time for incongruent vs. congruent trials of OCD patients and healthy controls on all trials (left panel) and as a function of congruency on the previous (N-1) trial (center and right panels). Error bars represent one standard error from the mean. * - significant on $p < .001$ level. n.s. - not significant.

replications, and small effect sizes (Abramovitch, Abramowitz, & Mittelman, 2013). Some of these discrepancies across studies may be explained by the inclusion of samples of medicated and unmedicated patients, since medication might affect performance on executive control tasks (Kalanthroff et al., 2017; Simpson et al., 2006), and by inclusion of patients with varying degrees of comorbidity. That we did not find evidence for executive control deficits in conflict resolution on the Simon task adds to accumulating evidence that conflict resolution may be intact in unmedicated OCD patients (Kalanthroff et al., 2017; Simpson et al., 2006). At the same time, the Simon interference effect represents a specific executive function—control over location-based interference and response selection. Thus, the current findings do not exclude deficits in other executive functions (Kalanthroff, Abramovitch, Steinman, Abramowitz, & Simpson, 2016; Snyder et al., 2015). Furthermore, as seen in other anxiety disorders (Kalanthroff, Henik, Derakshan, & Usher, 2016), OCD participants might show deficits in conflict resolution when responding to emotional stimuli.

In contrast, we did find that OCD patients exhibited a larger Gratton effect compared to HCs, indicating heightened conflict monitoring in these patients. Interestingly, over 30 years ago, Pitman (1987) suggested that OCD symptoms may be linked to hyperactive conflict monitoring. Consistent with this suggestion, Abramovitch et al. (2011) suggested that the executive control system of OCD patients is always on high alert, trying to execute control over intrusion. The current study provides experimental evidence for this suggestion in a large group of unmedicated OCD patients. If OCD patients are always on high alert, this may come at an experimentally detectable cost in processing efficiency, as has been seen in individuals with anxiety (Eysenck & Calvo, 1992). A deficit in task performance in OCD patients may thus appear only when using a demanding cognitive control (or a concurrent) task. Notably, two potential explanations could account for our finding of a larger Gratton effect compared to HCs and should be explored in future studies: (a) OCD patients may *recruit more control* following a conflict-laden trial, or (b) OCD patients may be *slower to relax* their control system after encountering conflict.

That OCD patients have a large Gratton effect also suggests that these patients are able to dynamically adapt their control levels. Interestingly, early studies suggested that OCD is characterized by general rigidity (e.g., Stein, 2002), by inflexible adjustment to frequent changes in task contingencies (e.g., Wisconsin[2] card sorting task (e.g., Lucey et al., 1997), set-shifting task (e.g., Gu et al., 2008; Meiran, Diamond, Toder, & Nemets, 2011), and by inflexible executive control (Soref et al., 2008). Our data do not indicate such rigidity or inflexibility, as dynamic adaption of executive control was found to be even more pronounced than in HCs. Of note, a recent meta-analysis that reviewed flexibility measures from behavioral tasks found no evidence for inflexibility in OCD (Fradkin, Strauss, Pereg, & Huppert, 2018).

To conclude, we demonstrated that unmedicated OCD participants show a similar interference effect but a larger Gratton effect than their healthy counterparts. These data add to the accumulating evidence indicating that conflict resolution is not globally deficient in OCD patients and provide direct evidence that conflict monitoring is heightened in OCD patients. Importantly, our sample is mostly comprised of patients with moderate symptom-severity, thus the conclusions from the current study should be tested in a sample with more severe symptoms. Nevertheless, our results challenge the assumption of cognitive inflexibility in OCD and highlight the importance of studying unmedicated subjects when investigating executive control.

Author contributions

Eyal Kalanthroff: Conceptualization, Validation, Formal analysis, Writing - Original Draft, Visualization. Rachel Marsh: Conceptualization, Methodology, Software, Investigation, Resources, Data Curation, Writing - Review & Editing, Funding acquisition. Ran R. Hassin: Writing - Review & Editing. Helen Blair Simpson: Conceptualization, Methodology, Software, Investigation, Resources, Data Curation, Writing - Review & Editing, Funding acquisition, Supervision.

Declaration of competing interest

Dr. Simpson has received royalties from Cambridge University Press and UpToDate, Inc and is currently receiving research support from Biohaven for a multi-site clinical trial. The remaining authors declare no potential conflict of interest.

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