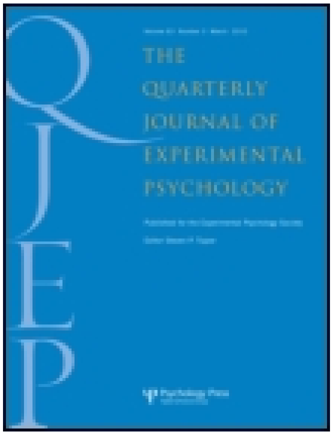

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Stop interfering: Stroop task conflict independence from informational conflict and interference

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Stop interfering: Stroop task conflict independence from informational conflict and interference

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Performance of the Stroop task reflects two conflicts—informational (between the incongruent word and ink colour) and task (between relevant colour naming and irrelevant word reading). This is supported by findings showing that the anterior cingulate cortex is more activated by congruent and incongruent stimuli than by nonword neutral stimuli. Previously, researchers demonstrated behavioural evidence for task conflict—a reverse facilitation effect under a reduced task conflict control condition. The boundary conditions of this Stroop reverse facilitation effect are not yet clear. The current study aimed to investigate whether task conflict arises, and task control is needed, whenever there are two possible tasks, even if the irrelevant task cannot mislead one to give erroneous responses (i.e., stimuli do not contain an informational conflict). To this end, in both experiments no incongruent stimuli were presented. In Experiment 1, participants conducted a Stroop task with a high proportion of nonword neutrals and with a neutral/congruent cue in 50% of the trials. In Experiment 2, the nonword neutral was replaced by a real non-colour-word. We found the reverse facilitation effect in the noncued trials of Experiment 1. Moreover, as expected, this effect was eliminated when a noncolour neutral word that induced task conflict was used (Experiment 2). We conclude that task conflict control is reactively activated whenever there are at least two possible tasks, even in the absence of any possibility of informational conflict.

Keywords: Task conflict; Stroop; Reverse facilitation; Executive functions; Anterior cingulate cortex.

Executive control is a key human function that mediates the ability to guide behaviour in accordance with internal goals (Banich, 2009; Miller & Cohen, 2001; Miyake et al., 2000; Shallice & Norman, 1986). An important part of this process, and perhaps a hallmark of executive function, is the suppression of irrelevant information (Verbruggen & Logan, 2008). This is needed in daily situations that go against routine. To study this process in the laboratory, consider the Stroop task (Stroop, 1935), which requires participants to identify the colour in which a colour-word is printed, while ignoring the word meaning. Since word-reading is automatic, this presents participants with a challenge when presented with incongruent stimuli (e.g., GREEN written in red). In

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such cases, one has to ignore the irrelevant word (GREEN) and respond instead to the colour (red). The Stroop effect (i.e., longer reaction time, RT, for incongruent than for congruent stimuli; e.g., RED written in red) and interference effects (i.e., slower RT for incongruent than for neutral stimuli; e.g., XXXX written in red) demonstrate that participants have difficulty in ignoring the irrelevant word altogether. The low error rate in normal participants and the increased error rate in participants with executive and frontal deficits (Cohen & Servan-Schreiber, 1992) demonstrate the role of executive control and of the prefrontal cortex in guiding task-relevant behaviour and suppressing automatic responses (Cohen, Dunbar, & McClelland, 1990).

A number of investigations have suggested that executive control is allocated in an adaptive and strategic way in response to conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; De Pisapia & Braver, 2006). This means that participants do not allocate executive control equally in all Stroop trials; rather, control relaxes after easy (neutral) stimuli, but is engaged by difficult, conflict-inducing (incongruent) stimuli. This suggestion is supported by data showing that the magnitude of the Stroop effect increases in blocks that have a majority of neutrals (e.g., 12.5% incongruent, 12.5% congruent, and 75% neutrals), compared to blocks that have a majority of colour-word Stroop stimuli (e.g., 37.5% incongruent, 37.5% congruent, and 25% neutral; Tzelgov, Henik, & Berger, 1992). As suggested by Tzelgov et al. (1992), and consistent with a role of conflict in the allocation of executive control in the Stroop task, an increase in the frequency of neutrals may result in putting executive control *to sleep,* resulting in enhanced Stroop interference. This interpretation is supported by neuroimaging data that provide evidence for the role of conflict in top-down control regulation by showing that the anterior cingulate cortex (ACC)—a brain area thought to monitor conflict (Botvinick et al., 2001; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter, Botvinick, & Cohen, 1999; Carter et al., 1998)—is more active in incongruent Stroop trials than in neutral trials (e.g., Bench et al., 1993; Carter, Mintun, & Cohen, 1995; Milham et al., 2002, for older participants). Interestingly, however, these studies also show that not only do the incongruent Stroop stimuli trigger higher ACC activations than the neutrals do, but the congruent Stroop trials do so too. This may be surprising since on the face of it, responding to such stimuli should be easy, as indicated by facilitation effects (faster response to congruent than to neutral Stroop stimuli; MacLeod, 1991). One may note, though, that Stroop facilitation effects are generally smaller and less robust than Stroop interference effects (e.g., Dalrymple-Alford & Budayr, 1966).

The nature of the contradiction between the neuroimaging and the behavioural data on conflict and putative facilitation in Stroop congruent trials has been subject to a number of recent investigations. One way to resolve this apparent contradiction is to distinguish between two types of conflict: information (or response; i.e., a conflict between the contradictory information that arises from the word meaning and the information that arises from the word colour) versus *task conflict* (i.e., a conflict between the relevant identification of the colour task and the irrelevant but automatic reading task). While information conflict involves the content of the stimulus and the response needed, differing between congruent and incongruent Stroop stimuli, task conflict involves the task associated with the stimulus and differs between congruent and neutral nonword Stroop stimuli (Kalanthroff, Goldfarb, & Henik, in press). This is consistent with the suggestion that a stimulus has the ability to evoke performance of a task that has a strong association with it (Allport & Wylie, 2000; Rogers & Monsell, 1995; Waszak, Hommel, & Allport, 2003) and, specifically, that words trigger an automatic tendency to read written words (MacLeod & MacDonald, 2000). Such task conflict may arise in particular in situations in which the proactive top-down control mechanism (Braver, 2012) is diminished. In these situations, the stimulus may trigger a reactive response of the associated task demands.

Recent research in our lab provided further support for the presence of task conflict in congruent Stroop stimuli by demonstrating a novel *reverse facilitation* effect (i.e., faster response to nonword neutrals, e.g., XXXX written in red, than to congruent Stroop stimuli, e.g., RED written in red). To show this, Goldfarb and Henik (2007) used a high-neutral-nonword-frequency, low-control condition, as a manipulation aimed to *put the task conflict guard to sleep*. To further reduce proactive task control, they used a cueing procedure in which in half of the trials a valid cue indicated whether the upcoming trial was going to be a neutral or a colour-word trial. This allowed participants to relax the proactive control progressively further as they got used to relying on cues for activating it. The results led to a slow-down in RTs for congruent compared to nonword neutral trials—that is, a significant reverse facilitation in the noncued trials. Because the large proportion of neutral trials and cueing were the cause for the changes in RTs in congruent trials, these results provided behavioural evidence for task conflict between responding to the word reading task and responding to the colour naming task. The reverse facilitation revealed that the task conflict is present in congruent Stroop trials in the absence of proactive control (noncued condition), in line with the neuroimaging evidence (e.g., Bench et al., 1993; Carter et al., 1995).

One important question arises, however, regarding the boundary conditions of the Stroop reverse facilitation, which has implications for the nature of the task conflict slow-down. Is this slow-down an adaptive control process, meant to protect the participant from the risk of making a mistake in incongruent Stroop trials (half of the colour-word trials were incongruent in all the studies above)? Or, is the task conflict slow-down a mandatory and automatic process that is triggered by the presence of any word-like stimuli, even if no danger for misleading information exists, as long as a competing task exists (e.g., a word in the Stroop task)? If the latter is the case, we should expect that the Stroop reverse facilitation be maintained, even if there are no incongruent Stroop trials at all. It has been suggested that the Stroop effect is sensitive to context (Melara & Algom, 2003; Sabri, Melara, & Algom, 2001). Will there be an indication for task conflict when incongruent trials are nonexistent? Accordingly, the aim of this study is to test the boundary condition of the Stroop reverse facilitation. Will participants have slowed-down responses in congruent Stroop trials even though the irrelevant pathway will activate the same response, and no potential danger will be present? Such a nonadaptive outcome is consistent with studies indicating that the Stroop task conflict is independent of informational conflict and that the reading task is automatically activated whenever there is a real word presented. For example, in a neuroimaging Stroop study, Bench et al. (1993) presented stimuli in pure blocks of congruent or neutral (i.e., letter string) trials. Even though they used pure blocks, they still found larger ACC activation for a pure congruent block than for a pure neutral block, indicating that task control is not adaptive and that task conflict arises even if there is no danger for incongruent information. Bench et al.'s findings are restricted to the neural level since at the behavioural level they found a common (small) facilitation. In the current study, we aim to test this at the behavioural level.

EXPERIMENT 1

Our study is based on the experimental design used by Goldfarb and Henik (2007). In their study, 75% of the trials were neutral, 12.5% congruent, and 12.5% incongruent. In half of the trials, subjects were presented a cue telling them whether the upcoming trial was going to be neutral or not. The automatic response to the word (reading) could potentially cause an erroneous response; hence, it was worthwhile inhibiting this irrelevant task.

In this case, performing the irrelevant task can lead to some "bad consequences". Efforts invested in inhibiting the automatic task (or managing the task conflict) slowed the RTs for congruent trials and caused a reverse facilitation effect. But, what would happen had the participants learned that the competing task could never mislead them? In this experiment, we replicated the procedure from our previous study (Goldfarb & Henik, 2007), only with no incongruent trials. This would allow us to answer the question of whether task conflict is automatically triggered whenever a written word appears or whether control is adaptive and stops managing that conflict if it learned that it is not worthwhile.

Since we believe that task conflict exists whenever there are (at least) two possible tasks and that this conflict will appear whenever proactive control is low, we expect to replicate Goldfarb and Henik's (2007) finding. That is, in a high neutral nonword condition, proactive task conflict control is expected to be relaxed, and therefore in noncued trials, task conflict should be present, as indicated by a reverse facilitation. In the same high neutral nonword condition, in cued trials control can be easily and efficiently recruited, and, thus, task conflict is less likely to appear; hence, we do not expect a reverse facilitation.

Unlike in Goldfarb and Henik's (2007) study, the cue in our experiment revealed whether the upcoming trial was going to be neutral or congruent. We address the potential problems that this could cause as well as our suggested solutions in the Discussion section of the current experiment and in Experiment 2.

Method

Participants

Nineteen first-year psychology students (15 females and 4 males) of Ben-Gurion University of the Negev (Israel) participated for partial fulfilment of course requirements and credit. All participants had normal or corrected-to-normal vision, were right-handed, had no history of attention deficit or dyslexia, and were native speakers of Hebrew, and all were naive as to the purpose of the experiment. One participant (male) was excluded from further analysis due to extremely slow RT (average RTs were more than 3 standard deviations from the mean in all conditions).

Stimuli

Participants were presented with a four-colour, manual Stroop task. Each stimulus consisted of one of four colour-words (blue, red, green, and yellow), or a four-letter string in Hebrew—שששש (meaningless repetition of a Hebrew letter, parallel to XXXX in the English version). All four colour-words have four letters in Hebrew. The ink colour was red, blue, green, or yellow. There were four different congruent combinations of words and ink colours, and four different neutral stimuli. An "X" cue meant that a congruent trial was going to appear, an "O" cue meant that a neutral letter string was going to appear, and a "?" cue meant that any stimulus could appear. Cues were 100% valid. Seventy-five percent of the trials were neutral (37.5% cued and 37.5% noncued), and 25% were congruent (12.5% cued and 12.5% noncued). The words were presented at the centre of a screen on a black background and were 0.98 inches high and 2.36 inches wide. Cues were presented at the centre of the screen.

Procedure

For most accounts the procedure was similar to that in Goldfarb and Henik's (2007) study. Data collection and stimuli presentation were controlled by a DELL OptiPlex 760 vPro computer with an Intel core 2 duo processor E8400 3 GHz. Stimuli were presented on a DELL E198PF 19″ LCD monitor. A keyboard was placed on a table between the participant and the monitor. Participants were tested individually. They sat approximately 23.5″ from the computer screen. Coloured stickers were taped on four regular keyboard keys according to the colours they represented. The "v" key represented red, the "b" key represented blue, the "n" key represented green, and the "m" key represented yellow. Participants were asked to use only their right hand.

The experiment started with 12 key-matching practice trials. In these trials, a coloured asterisk appeared at the centre of the screen, three times in each of the four colours, in a random order. The asterisk disappeared on a key-press or after 3,500 ms, and then the next trial began after a 1,000-ms interval. Feedback was given only for incorrect trials.

Following this, participants were presented with an explanation about the task and the meaning of the cues. Instructions emphasized that after an "O" cue a letter string would appear, after an "X" cue a colour-word would appear, and after a "?" cue either one of the two could appear. Participants were asked to refer only to the ink colour and to press the correct key as fast as possible without making mistakes. Instructions did not reveal that there would be no incongruent trials or the proportion of the congruency conditions. Nevertheless, participants were told that the practice block would be identical to the experimental block (only that the experimental block would be longer and would not include feedback); so in fact, participants knew there would be no incongruent trials after the practice block. Subjects underwent 32 practice trials (which were not analysed further) and 192 experimental trials. In both the experiment block and the practice block, 25% of the trials were congruent, and 75% were neutral. Half of the trials in each congruency condition were cued (i.e., "X" or "O" preceded the target), and half were not ("?" preceded the target). Within each condition, the stimuli were presented equally. The order of the trials was random.

Each trial started with a 1,000-ms fixation (a white + sign at the centre of a black screen), followed by a 500-ms interval of an empty black screen. Then the cue appeared for 1,000 ms, followed by another 500-ms interval of an empty black screen. After this the Stroop target appeared and stayed in view for 2,500 ms or until a keypress. RT was calculated from the appearance of the target Stroop stimulus to the reaction. Each trial ended with a 1,000-ms intertrial interval.

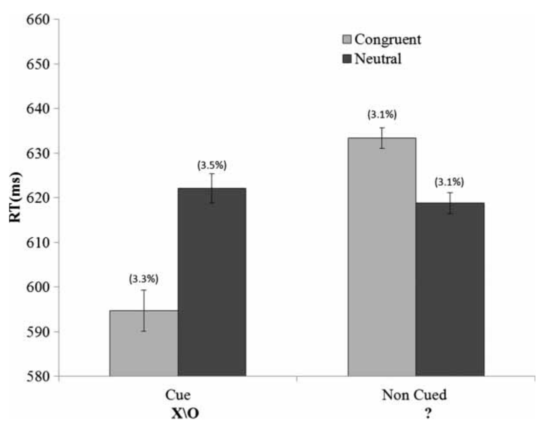

Figure 1. *Mean RT (reaction time) and error rates (in parentheses) in the congruency conditions for Stroop trials with and without cueing in Experiment 1. Error bars represent one standard error from the mean (using Cousineau's, 2005, method to compute the error bars in within-subjects designs).*

Results and discussion

Mean RTs of correct responses were calculated for each participant in each condition. A two-way ANOVA (analysis of variance) with repeated measures was applied to RT data with congruency (congruent and neutral) and cue (cued or noncued) as within-subject factors. A significant interaction was found, $F(1, 17) = 7.616$, $MSE =$ 1,041.829, $p < .01$, $\eta_p^2 = .309$. In addition, we found a main effect for cue, $F(1, 17) = 6.420$, $MSE = 876.74$, $p < .05$, $\eta_p^2 = .274$, but no effect for congruency, $F(1, 11) < 1$. We found that RT for noncued congruent stimuli (633 ms) was 39 ms longer than that for cued congruent stimuli (594 ms), $t(17) = 3.161$, $p < .01$. On the other hand, there was no significant difference in RT between the cued (622 ms) and the noncued (619 ms) neutral trials $t(17) < 1$ (Figure 1).

To further investigate the interaction, a planned post hoc analysis was carried out. We analysed the simple effect of congruency in the two cueing conditions. For the cued condition, we found a marginally significant facilitation, $F(1, 17) = 3.631$, $MSE = 1{,}856.185$, $p = .074$. For the noncued condition, we found a significant reverse facilitation of 15 ms, $F(1, 17) = 5.46$, $MSE = 352.39$, $p < .05$. Note that two different patterns of Stroop effects were found within the same experiment. A reverse facilitation (RTs for neutral trials shorter than RTs for congruent trials) was found in the noncued condition, and the regular facilitation effect (RTs for neutral trials longer than RTs for congruent trials) was found when a cue was given (see Figure 1). Reverse facilitation in the noncued condition, which occurred without any incongruent trials, indicates that task conflict arises automatically whenever a word is presented, regardless of the information it contains. Moreover, the reverse facilitation effect also indicates that task conflict control is needed, and it slows down congruent RT responses, even when there are no incongruent trials, or when the competing task cannot mislead you. The lack of a reverse facilitation in the cued (higher control) condition also supports the interpretation that the task conflict effect is contingent upon low proactive control.

Using an ex-Gaussian analysis, Steinhauser and Hubner (2009) showed that a task conflict effect is obtained in the exponential (slow) portion of the RT distribution, while response conflict is obtained in the Gaussian (fast) portion of the RT distribution. In light of this, one can argue that task conflict disappeared in cued trials only due to speeding induced by the cue, and not due to increased proactive control. Though fast RTs and high control explanations do not necessarily contradict each other, we conducted an additional analysis in order to investigate this alternative explanation. Mean RTs (of correct responses) were calculated for congruent and neutral cued conditions only for the slowest quarter of the trials for each participant. Similar to the general RT analysis, we found a marginally significant common facilitation effect (62 ms), $F(1, 17) = 4.245$, $MSE = 8{,}051.369$, $p = .055$, indicating that the facilitation effect is not an artefact of generally fast RTs in the cued condition.

The most important finding of this experiment is that our results in the noncued condition replicate those of Goldfarb and Henik (2007) in a Stroop task without incongruent trials. In the cued condition, however, we found a marginally significant facilitation, whereas they found a marginally significant reverse facilitation. Furthermore, the magnitude of the reverse-facilitation effect in the noncued condition (about 15 ms) was smaller than the one found in Goldfarb and Henik's study (more than 100 ms). Although it is difficult to draw firm conclusions from the magnitude of the facilitation in different studies, one possibility is that the effect of the task conflict—the amount of inhibition it triggers on the response—depends to some degree on the correlation between task conflict and errors. While in Goldfarb and Henik's study task-conflict trials were those in which there was a danger to make an erroneous response (half were incongruent), in the present experiment, this was not the case (all task-conflict trials were congruent). Thus, it is possible that while task conflict is automatic, the amount of response inhibition it triggers depends on task contingencies (Melara & Algom, 2003; Sabri et al., 2001). We defer this question to future studies that vary the frequency of the incongruent stimuli in a within-subject design. The important result of our present study is that Stroop reverse facilitation emerges even under a stringent condition in which the congruent words do not pose any danger towards naming errors.

A possible alternative explanation for the result in the cued condition is that in the present study, participants switched to an explicit reading strategy in congruent trials. This could explain the faster RTs in the cued congruent trials. In order to reject this alternative explanation, we conducted an additional analysis. Allport, Styles, and Hsieh (1994) showed that there is a large switching cost (i.e., longer RTs to switch trials than to repeat trials) when, in the Stroop task, participants switched from a colour naming task to a word reading task. Because we wanted to rule out the possibility that participants responded to the word in the cued congruent trials, we looked for a switching (to word response) cost. If participants responded to the word, it is most likely that they did it in cued congruent trials, whereas in the neutral trials they surely responded to colours; thus, responding to a word on trial n would be longer if the preceding trial $n - 1$ was a neutral than when it was a word. Mean RTs (of correct responses) in the cued congruent condition were calculated separately for trials that were preceded by a cued congruent condition (repeat) and for trials that were preceded by neutrals (supposedly switch trials). No significant difference was found between "repeat" trials (589 ms) and "switch" trials (595 ms), $F < 1$ (the observed statistical power for this null effect was .06), indicating no switching cost (hence, no switching). Note that previous studies argued that when switching from reading to colour naming, there is no (or much less) switching cost (Allport et al., 1994); thus, we calculated "switching cost" caused by (possibly) switching to a word response.

We further discuss the possibility that participants responded to the word on cued congruent trials in the Discussion of Experiment 2.

EXPERIMENT 2

Experiment 2 was conducted in order to verify further that nothing but the level of task conflict control produced the effects observed in Experiment 1. In order to do this, we used a manipulation used in our previous studies (Goldfarb & Henik, 2007, Experiment 2; Kalanthroff et al., in press, Experiments 2 and 3). We replaced the neutral homogenous letter string stimulus in Experiment 1 with a non-colour-word. This would still allow for no informational conflict in the neutral condition. Using the Stroop task, Bugg, McDaniel, Scullin, and Braver (2011) found a decreased interference effect (increased proactive control) in a high-neutral-word-proportion block. This suggests that neutral words cause a conflict and require executive control. According to MacLeod and MacDonald (2000), words raise an automatic tendency to read; thus a non-colour-word should activate an automatic word reading response (the irrelevant task), whereas a string of letters should not. Goldfarb and Henik (2007), and Kalanthroff et al. (in press) found that the reverse facilitation effect indeed disappeared when a non-colour-word was used as a neutral. Accordingly, under this condition, task conflict should occur in all trials, and its effect should not be seen in any trial —task conflict control will be high in both cued and noncued conditions, and as in Goldfarb and Henik's (Experiment 2) and Kalanthroff et al.'s studies (Experiments 2 and 3), no task conflict effects will be revealed.

As we noted in Experiment 1, the cue effect could alternatively be attributed to the participants' strategy in which they switch to a reading task in the congruent cued trials. Experiment 2's design still allows participants to carry out this strategy. Theoretically, they can switch to a reading task in the congruent cued trials regardless of the kind of neutral trials used in the design. If participants used such a strategy, and the effect found in the cued condition of Experiment 1 had nothing to do with the task conflict, then the same pattern of results as those found in Experiment1 would be found in Experiment 2.

Because we believe that task conflict will now appear in both congruent and neutral trials, we predict that a common facilitation will appear in the noncued condition. Moreover, because we believe that participants follow the instructions and do not read (as also evidenced from the lack of switching cost in Experiment 1), we predict that in the cued condition the facilitation effect will not be larger than that in the noncued condition.

Method

Participants

Sixteen first-year Psychology students (12 females and 4 males) of Ben-Gurion University of the Negev (Israel), who did not take part in Experiment 1, participated for partial fulfilment of course requirements and credit. All participants had normal or corrected-to-normal vision, were right-handed, had no history of attention deficit or dyslexia, and were native speakers of Hebrew, and all were naive as to the purpose of the experiment.

Stimuli

In this experiment, the meaningless homogenous letter string *ששששש* was replaced by the Hebrew non-colour-word *בניין* (building), which matched the colour-words by length and word frequency and did not begin with the same letter as any of the colour-words (see also Goldfarb & Henik, 2007). Except for this, all the stimuli and the procedure in Experiment 2 were identical to those in Experiment 1.

Results and discussion

Mean RTs of correct responses were calculated for each participant in each condition. A two-way

ANOVA with repeated measures was applied to RT data with congruency (congruent and neutral) and cue (cued or noncued) as within-subject factors. As expected, a main effect for congruency was found, $F(1, 15) = 6.948$, $MSE = 1{,}580.698$, $p < .05$, $\eta_p^2 = .317$, and no main effect for cueing, $F < 1$, or interaction, $F < 1$, was found. The observed statistical powers for those null effects were .053 and .063 for the main effect for cueing and for the interaction, respectively. As can be seen in Figure 2, when using a neutral word, response to the cued and noncued conditions did not differ. It seems that under a high-control condition, caused by the continuous encounters with the need to manage the task conflict, task control was very efficient in quickly solving the task conflict.

Planned comparisons showed that in both the cued and the noncued conditions, RT for congruent words was significantly shorter (611 ms and 615 ms for the cued and noncued condition, respectively) than RT for neutral non-colour-words (640 ms and 639 ms for the cued and noncued conditions, respectively)—the facilitation effect, $F(1, 15) = 4.933$, $MSE = 1{,}334.38$, $p < .05$, and $F(1, 15) = 4.537$, $MSE = 991.377$, $p < .05$, respectively (Figure 2). Unlike in Experiment 1, task conflict control was high, and thus a common facilitation was demonstrated. It seems that word neutrals increase task conflict control because task control is needed in order to prevent responding to words.

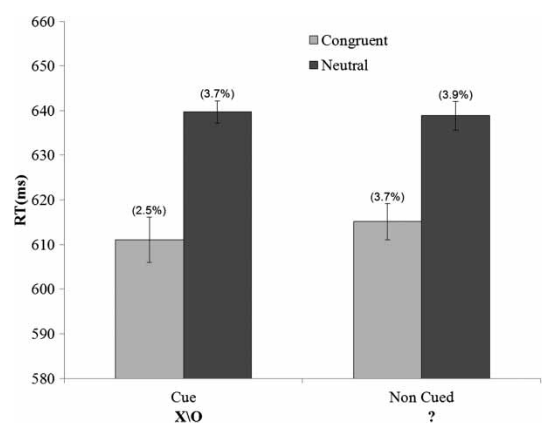

Figure 2. *Mean RT (reaction time) and error rates (in parentheses) in the congruency conditions for Stroop trials with and without cueing in Experiment 2. Error bars represent one standard error from the mean (using Cousineau's, 2005, method to compute the error bars in within-subjects designs).*

Importantly, Experiment 2 strengthens the assumption that results obtained in Experiment 1 were not caused by reading, or switching to reading, in the congruent trials. There are two indications that participants did not respond to the word in the congruent cued condition: (a) If reading had taken place in the congruent cued condition, participants would have used the same strategy in the parallel condition in Experiment 2. Hence, the facilitation effect should have been higher (or the RTs in congruent trials would have been shorter) in the cued condition than in the noncued condition in this experiment. Moreover, if switching from identifying the colour to reading was the cause for the reverse facilitation effect obtained in Experiment 1, we would have expected the same pattern of results in Experiment 2. The fact that the facilitation effect was positive and similar in both conditions (30 ms and 24 ms for cued and noncued condition, respectively) and that the interaction between congruency and cueing was not significant, does not support this option. (b) If participants switched to reading in the congruent cued condition, we would have expected a switching cost (Allport et al., 1994) in Experiment 1; no such switching cost was found.

Another important finding of Experiment 2 was that there was no main effect for cueing, meaning that the cue did not help to speed up responding. We suggested earlier that conflict arose whenever a word was presented. Accordingly, participants knew that a conflict was expected in each and every trial. Thus, the cue was not informative regarding the upcoming conflict. Additionally, since a conflict was presented in all trials (unlike Experiment 1 in which conflicts were rare), our results indicate that proactive control was high throughout the block. In Experiment 1, proactive control was relaxed, and the existence of cues weakened it even more. In Experiment 2, control was already high, and a cue did not make a difference.

Moreover, the idea that a high proportion of word neutrals increases proactive control is strengthened by Bugg et al.'s (2011) study that was mentioned earlier.

GENERAL DISCUSSION

The main result of this investigation is the replication of the Stroop reverse facilitation (faster RT to neutral stimuli than to congruent Stroop colour-words; Goldfarb & Henik, 2007), in a study that does not include any incongruent Stroop stimuli. This supports the idea that congruent Stroop stimuli trigger task conflict—between the relevant task and the irrelevant task that is triggered by a strong association with a stimulus—automatically.

These results are consistent with the idea that at least part of the interference that is commonly observed in Stroop tasks is due to competition between the relevant task and the irrelevant automatic task (Monsell, Taylor, & Murphy, 2001); they are also consistent with the results of more recent studies on task conflict in the Stroop task. For example, David et al. (2011) found evidence from an event-related potential (ERP) study for the existence of task conflict in the Stroop matching task; Steinhauser and Hubner (2009) showed an empirical dissociation between task conflict and response conflict in the Stroop task by showing that the task conflict effect is obtained in the exponential portion of the RT distribution, while response conflict is obtained in the Gaussian portion of the RT distribution; and finally, Bugg et al. (2011) showed decreased Stroop interference (evidence for increased proactive control) in a high-neutral-word-proportion condition, similar to that found in a high-incongruent-word-proportion condition—another indication that a written word causes control recruitment. This is consistent with the results of Experiment 2 of the current study in which the cue did not help participants to improve performance. In line with Bugg and colleagues, we suggest that a high proportion of word-neutral trials increases proactive control throughout the block. Evidence for task conflict was found in a few studies on task switching, a paradigm that increases load on proactive task maintenance control (e.g., Aarts, Roelofs, & van Turennouta, 2009; Braverman & Meiran, 2010). Thus, the existence of task conflict is supported by evidence from a number of converging paradigms.

In the Stroop task, the task conflict, unlike the informational conflict, exists in both congruent and incongruent trials. Goldfarb and Henik (2007) argued that a very efficient task control mechanism prevents the behavioural expression of the task conflict, which becomes visible under low-control conditions. In a recent study, Kalanthroff et al. (in press) combined the Stroop task with the stop-signal method (Logan, 1994; Logan & Cowan, 1984). Participants were presented with Stroop stimuli, but in some of the trials they were presented with a stop signal, requiring the inhibition of a response. If inhibition of the stop signal and inhibition of irrelevant (but automatic) pathways in the Stroop task involve a common process (Miyake et al., 2000), we should expect the two types of inhibitory control to be correlated. That is, when participants respond in spite of the stop signal (low inhibitory control), stopping fails, and the proactive Stroop control is diminished also. Indeed, we found that erroneous responses to stop-signal trials showed slower RTs to congruent than to neutral nonword Stroop trials—a reverse facilitation. Consistent with this, in an additional individual differences study (Kalanthroff & Henik, 2012), we found significant correlations between the Stroop facilitation effect and stop-signal reaction time (SSRT). These results (Stroop reverse facilitation in the absence of proactive task control) are further supported by developmental studies with Stroop-like tasks, which reported behavioural evidence for task conflict in children (La Heij & Boelens, 2011; La Heij, Boelens, & Kuipers, 2010; see Discussion section).

Crucially, all of these studies used incompatible trials so that acting on the competing task could potentially lead one to an incorrect response. Hence, it was impossible to determine whether task control depended on the existence of incongruent trials in the design—namely, whether it emerged automatically, even in the case where no danger for incongruent information existed. In contrast, the current work shows that task conflict appears automatically, even when the competing task (i.e., reading) could not lead to errors.

The current findings strengthen the claim that stimuli have the ability to evoke the performance of a task that has a strong association with them (Allport & Wylie, 2000; Rogers & Monsell, 1995; Waszak et al., 2003). In our previous work (Kalanthroff et al., in press), which was mentioned earlier, we found a reverse facilitation effect in erroneous response to stop-signal trials. Interestingly, RTs for incongruent trials were not longer than RTs for congruent trials in these erroneous responses. We concluded that at least some dissociation between two separate control mechanisms exists; the first control mechanism is responsible for managing the task conflict and is recruited when a task conflict appears; the second is responsible for solving the informational conflict and is recruited when facing stimuli that produce incongruent information. Our previous findings showed that failure in the task control mechanism is not necessarily followed by a failure in the informational control mechanism. Results in the current study strengthen this by showing that task conflict occurs even if there is no potential for informational conflict.

Even though we basically replicated the main findings of Goldfarb and Henik (2007) in which a significant reverse facilitation was observed in the noncued condition, there were still some differences between the current study results (in which incongruent trials were omitted) and the previous ones (in which incongruent trials were present) regarding the cued condition. In the current study, in both experiments a common facilitation effect was obtained under the cued condition (though it was only marginally significant in Experiment 1), whereas in Goldfarb and Henik's study, under the cued condition there was no facilitation effect but rather a nonsignificant reverse facilitation. As the magnitude of the reverse facilitation effect was smaller than that obtained in studies that mixed incongruent stimuli, there is a possibility that the magnitude of the response inhibition triggered by the task conflict depends on the relation between task conflict and error-prone (incongruent) responses. This might imply that task control is adaptive to some extent; when there are no incongruent trials, there is less task conflict, slowing down the RTs for congruent trials less than when incongruent trials exist. An adaptation might occur after subjects learn that no incongruent trials exist, and, thus, the reading task interferes less. In the cued condition, task control is not relaxed enough, and thus, its (low) levels are sufficient to prevent the reverse facilitation.

Though the current study implies that task conflict emerges in congruent trials, it seems that the system can detect that the competing task is less dangerous, and, hence, less control is needed. It takes a more "relaxing effort" of proactive control in order to reveal the task conflict (or reverse facilitation). Importantly, our design does not allow us to draw unequivocal conclusions about the existence and characteristics of a subtle adaptation mechanism (Melara & Algom, 2003). Future research that varies the proportion of incongruent trials in a within-subject design is needed to further examine this issue. Over all, we believe that the facilitation effect in the cued condition supports our suggestion that task control is contingent upon low (noncued condition) proactive control.

Braver and colleagues (Braver, 2012; De Pisapia & Braver, 2006) suggested two modes of cognitive control: proactive control, which "reflects the sustained and anticipatory maintenance of goal-relevant information", and reactive control, which "reflects transient stimulus-driven goal reactivation . . . based on interference demands or episodic associations" (Braver, 2012, p. 106). When the proportion of nonword neutrals is high, proactive control is likely to be less active due to long-term adaptation. It is reasonable to assume that low activation of proactive control is the cause for the appearance of behavioural evidence for the task conflict. Our finding seems to imply that task control is reactive (when the frequency of nonword neutrals is high, and cues are used to warn of upcoming Stroop stimuli) and is recruited whenever task conflict surprises subjects in a specific trial. However, when proactive control is high, the task conflict is managed very fast; hence, there is almost no behavioural evidence for it. Nevertheless, we also found indications for long-term adaptations; hence, we suspect that proactive control influences the activation of reactive control. The model proposed by De Pisapia and Braver (2006) accounts for this specific notion.

To conclude, we found that task conflict occurs, and that task control is needed, whenever there are at least two possible tasks. This is the case even if there is no possible informational conflict and even if the competing tasks cannot mislead one to an erroneous response. Though task conflict occurs even if there are no incongruent trials, we believe there is lower task conflict under this condition than where there are incongruent trials. This could possibly be explained by the common activation of the ACC by the task conflict and informational conflict; activation of this conflict detector mechanism is lower when there is no informational conflict. These results indicate that task conflict, together with the informational conflict, mediates Stroop performance.

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REFERENCES

Aarts, E., Roelofs, A., & van Turennouta, M. (2009). Attentional control of task and response in lateral and medial frontal cortex: Brain activity and reaction time distributions. *Neuropsychologia, 47*, 2089–2099.

Allport, D. A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV* (pp. 421–452). Hillsdale, NJ: Lawrence Erlbaum Associates.

Allport, A., & Wylie, G. (2000). Task-switching, stimulus–response bindings and negative priming. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 35–70). Cambridge, MA: MIT Press.

Banich, M. T. (2009). Executive function: The search for an integrated account. *Current Directions in Psychological Science, 18*, 89–94.

Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S., et al. (1993). Investigations of the functional anatomy of attention using the Stroop test. *Neuropsychologia, 32*, 907–922.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652.

Botvinick, M. M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*, 179–181.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*, 106–113.

Braverman, A., & Meiran, N. (2010). Task conflict effect in task switching. *Psychological Research, 74*, 568–578.

Bugg, J. M., McDaniel, M. A., Scullin, M. K., & Braver, T. S. (2011). Revealing list-level control in the Stroop task by uncovering its benefits and a cost. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1595–1606.

Carter, C. S., Botvinick, M. M., & Cohen, J. D. (1999). The contribution of the anterior cingulated cortex to executive processes in cognition. *Reviews in Neuroscience, 10*, 49–57.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science, 280*, 747–749.

Carter, C. S., Mintun, M., & Cohen, J. D. (1995). Interference and facilitation effects during selective attention: An H215O PET study of Stroop task performance. *NeuroImage, 2*, 264–272.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97*, 332–361.

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review, 99*, 45–77.

Cousineau, D. (2005). Confidence intervals in within-subjects designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology, 1*, 42–45.

Dalrymple-Alford, E. C., & Budayr, B. (1966). Examination of some aspects of the Stroop color-word test. *Perceptual and Motor Skills, 23*, 1211–1214.

David, I. A., Volchan, E., Vila, J., Keil, A., de Oliveira, L., Faria-Júnior, A. J. P., et al. (2011). Stroop matching task: Role of feature selection and temporal modulation. *Experimental Brain Research, 208*, 595–605.

De Pisapia, N., & Braver, T. S. (2006). A model of dual control mechanisms through anterior cingulate and prefrontal cortex interactions. *Neurocomputing, 69*, 1322–1326.

Goldfarb, L., & Henik, A. (2007). Evidence for task conflict in the Stroop effect. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1170–1176.

Kalanthroff, E., Goldfarb, L., & Henik, A. (in press). Evidence for interaction between the stop-signal and the Stroop task conflict. *Journal of Experimental Psychology*: *Human Perception and Performance*. doi: 10.1037/a0027429.

Kalanthroff, E., & Henik, A. (2012). *Individual but not fragile: Individual differences in task control predict Stroop facilitation*. Manuscript submitted for publication.

La Heij, W., & Boelens, H. (2011). Color–object interference: Further tests of an executive control account. *Journal of Experimental Child Psychology, 108*, 156–169.

La Heij, W., Boelens, H., & Kuipers, J. R. (2010). Object interference in children's colour and position naming: Lexical interference or task-set competition? *Language and Cognitive Processes, 25*, 568–588.

Logan, G. D. (1994). On the ability to inhibit thought and action: A user's guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 189–239). San Diego, CA: Academic Press.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91*, 295–327.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163–203.

MacLeod, C. M., & MacDonald, P. A. (2000). Interdimensional interference in the Stroop effect: Uncovering the cognitive and neural anatomy of attention. *Trends in Cognitive Sciences, 10*, 383–391.

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review, 110*, 422–471.

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., et al. (2002). Attentional control in the aging brain: Insights from an fMRI study of the Stroop task. *Brain & Cognition, 49*, 277–296.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167–202.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Monsell, S., Taylor, T. J., & Murphy, K. (2001). Naming the color of a word: Is it responses or task sets that compete? *Memory and Cognition, 29*, 137–151.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Sabri, M., Melara, R. D., & Algom, D. (2001). A confluence of contexts: Asymmetric versus global failures of selective attention to Stroop dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 515–537.

Shallice, T., & Norman, D. (1986). Attention to action: Willed and automatic control of behavior. In R. Davidson, G. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory* (Vol. 4, pp. 1–18). New York, NY: Plenum Press.

Steinhauser, M., & Hubner, R. (2009). Distinguishing response conflict and task conflict in the Stroop task: Evidence from ex-Gaussian distribution analysis. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1398–1412.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.

Tzelgov, J., Henik, A., & Berger, J. (1992). Controlling Stroop effects by manipulating expectations for color words. *Memory & Cognition, 20*, 727–735.

Verbruggen, F., & Logan, G. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences, 12*, 418–424.

Waszak, F., Hommel, B., & Allport, D. A. (2003). Task switching and long-term priming: Role of episodic stimulus–task bindings in task-shift costs. *Cognitive Psychology, 46*, 361–413.