Now You See It, Now You Don't:

Controlling for Contingencies and Stimulus Repetitions Eliminates the Gratton Effect

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Abstract

The Gratton (or sequential congruency) effect is the finding that conflict effects (e.g., Stroop and Eriksen flanker effects) are larger following congruent trials relative to incongruent trials. The standard account given for this is that a cognitive control mechanism detects conflict when it occurs and adapts to this conflict on the following trial. Others, however, have questioned the conflict adaptation account and suggested that sequential biases might account for the Gratton effect. In two experiments, contingency biases were removed from the task and stimulus repetitions were deleted to control for stimulus bindings. This eliminated the Gratton effect in the response times in both experiments, supporting a non-conflict explanation of the Gratton effect. A Gratton effect did persist in the errors of Experiment 1; however, this effect was not produced by the type of errors (word reading errors) that a conflict adaptation account should predict. Instead, tentative support was found for a congruency switch cost hypothesis. In all, the conflict adaptation account failed to account for any of the reported data. Implications for future work on cognitive control are discussed.

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Learning processes mould behaviour via knowledge about the contingency between (Lewicki, 1985, 1986; Schmidt, 2010; Schmidt, Crump, Cheesman, & Besner, 2007; Schmidt & Besner, 2008; Schmidt, De Houwer, & Besner, 2010) or sequence of (Hommel, 1998; Nissen & Bullemer, 1987) events we encounter in our environment. The role of cognitive control processes on our performance and behaviour has also been intensely studied in cognitive psychology (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Cohen, Dunbar, & McClelland, 1990; Cohen & Hudson, 1994; Norman & Shallice, 1986; Rabbitt, 1966). Often debate can be quite heated as to whether a given result reported in the literature is due to learning processes, cognitive control processes, or some combination of the two (e.g., see Blais & Bunge, 2010; Schmidt, 2010). One such result is the Gratton effect. Initially proposed as a cognitive control effect (Gratton, Coles, & Donchin, 1992), several researchers have challenged this view (e.g., Mayr & Awh, 2009; Mayr, Awh, & Laurey, 2003). This paper will present what we feel to be clear evidence that the Gratton effect results from non-conflict task biases (primarily contingency and stimulus repetition biases).

Stimulus Conflict and Cognitive Control

Several paradigms exist for studying stimulus conflict. One of these is the Stroop task (Stroop, 1935; see MacLeod, 1991, for a review), in which participants typically respond slower and less accurately to the print colour of a colour word if the word and colour are incongruent (e.g., the word GREEN printed in blue; GREEN$_{blue}$) rather than congruent (e.g., BLUE$_{blue}$). Similar congruency effects are observed in the Simon task (Simon & Rudell, 1967), where an irrelevant distracting location (e.g., left) interferes with a localized response (e.g., a right key press). Yet another paradigm is the Eriksen flanker task (Eriksen & Eriksen, 1974), where irrelevant flanking letters interfere with responding to a target letter (e.g., a distracting "b" to the

left and the right of a target "c"). Work with paradigms such as these demonstrates that unintentional processing of distracting information has an important impact on performance in the intended task.

While the impact of unintentional processes on behaviour in stimulus conflict tasks is unequivocal, many researchers are interested in the role of controlled behaviour on moderating performance in these tasks. One effect studied in this regard is the Gratton effect. The Gratton effect is the finding that congruency effects are larger following congruent relative to incongruent trials. This effect was first observed in the Eriksen flanker task by Gratton and colleagues (1992), but has also been observed in other tasks such as the Stroop task (e.g., Mayr & Awh, 2009; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006). The standard account of the Gratton effect, termed the *conflict adaptation account,* is that participants detect conflict on incongruent trials and decrease attention to the word on the following trial in order to avoid further conflict. As a result, the Stroop effect will be smaller. In contrast, on congruent trials there is no conflict, so attention will not be as constrained on the following trial. Hence, the word can interfere more strongly and the Stroop effect will be larger. Due to these processes, a Gratton effect will emerge, that is, an interaction between congruency on the current trial and congruency on the previous trial ($n - 1$ congruency). As will be discussed in the following section, although by far the most popular account of the Gratton effect, the conflict adaptation account has not gone unchallenged.

Stimulus Binding Biases

There are a whole series of confounds present in standard Stroop paradigms that can lead toward an interaction between congruency and $n - 1$ congruency in the absence of conflict adaptation. Essentially all of these confounds bias the interaction in the same direction, that is, in the direction of a Gratton effect. Several of them have already been studied. The first one is related to stimulus binding effects. Hommel (1998) observed that participants respond more

quickly to trials in which both the distracting and target stimulus dimensions alternate (e.g., $BLUE_{red}$ followed by $GREEN_{yellow}$; $BLUE_{red} \rightarrow GREEN_{yellow}$) or both repeat (e.g., $BLUE_{red} \rightarrow BLUE_{red}$) relative to when one, but not both of the stimulus dimensions repeat (e.g., $BLUE_{red} \rightarrow BLUE_{yellow}$ or $BLUE_{red} \rightarrow GREEN_{red}$). The claimed reason for the impairment of performance on these partial repetition trials is that repetition of one stimulus dimension (e.g., the word) leads to retrieval of the previous binding (e.g., $BLUE_{red}$), which conflicts with the processing of the current stimulus (e.g., $BLUE_{yellow}$).

Mayr and colleagues (2003) pointed out that stimulus repetitions, alternations, and partial repetitions are not equally prevalent in the four crucial conditions used for assessing the Gratton effect. They found that after analysing alternation trials only (i.e., trials in which both the word and colour change), the Gratton effect disappeared. Subsequently, however, other work has demonstrated that Gratton effects, though weakened, can be observed even after word-word and colour-colour repetitions are removed (Freitas, Bahar, Yang, & Bahar, 2007; Kerns, Cohen, MacDonnald, Cho, Stenger, & Carter, 2004; Notebaert et al., 2006). Further work has also removed word-colour repetitions (i.e., negative priming trials; e.g., $BLUE_{red} \rightarrow GREEN_{blue}$) and colour-word repetitions ($BLUE_{red} \rightarrow RED_{yellow}$), with results again showing a reduction but not elimination of the Gratton effect (Akçay & Hazeltine, 2007; Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006).

Sequential Contingency Biases

Contingency biases (Schmidt, in press) are a second confound that have been shown to artificially elevate the size of the Gratton effect. Experimenters often present distracting colour words more often in their congruent colour than would be expected by chance. For instance, in a four-choice task BLUE might be presented in blue 50% of the time, where chance would be 25%. This is problematic because Schmidt and colleagues (2007) have shown that participants learn

these contingencies and respond faster and more accurately to high contingency trials (i.e., where the word is presented in its most frequent colour) relative to low contingency trials (i.e., where the word is presented in an unexpected colour). If words are presented most often in their congruent colours, then congruency and contingency are perfectly confounded: congruent trials are high contingency and incongruent trials are low contingency. This is also true on the preceding ($n - 1$) trial: $n - 1$ congruent trials are high contingency and $n - 1$ incongruent trials are low contingency. Schmidt and colleagues have further shown that *contingency* and $n - 1$ *contingency* (i.e., contingency on the previous trial) interact. Specifically, the contingency effect (low contingency – high contingency) is larger following high contingency trials than following low contingency trials. Thus, Gratton experiments with contingency confounds will be biased by a sequential contingency effect.

There are several possible reasons why a sequential contingency effect might occur. One account, superficially similar to the conflict adaptation account, is that participants increase attention to the word following a correct response prediction. The word correctly predicts the response on high contingency trails (e.g., for $BLUE_{blue}$, where BLUE is presented most often in blue), thus leading to more attention to the word on the following trial, making for a larger contingency effect. In contrast, the word does not correctly predict the response on low contingency trials (e.g., for $BLUE_{red}$), thus leading to less attention to the word on the following trial, making for a smaller contingency effect. Note that the attentional modulation component of this account is only superficially similar to the conflict adaptation account, as the system is proposed to shift attention based on response expectancy and not based on conflict (i.e., congruency).

Another, non-attentional explanation for the sequential contingency effect could be stimulus sequence biases. Participants respond faster to predictable sequences of trials (Nissen &

Bullemer, 1987) and participants will see a sequence of any two given high contingency trials more frequently than a series of any two given low contingency trials. For instance, because the high contingency trials $BLUE_{blue}$ and $GREEN_{green}$ are presented quite frequently, participants will very often see the sequence $BLUE_{blue} \rightarrow GREEN_{green}$. In contrast, they will much less frequently see a sequence such as $BLUE_{red} \rightarrow GREEN_{green}$ or $GREEN_{green} \rightarrow BLUE_{red}$, given that the stimulus $MOVE_{red}$ appears only infrequently. Indeed, such sequences violate the expectation of the stimuli likely to follow or precede a given high contingency trial (i.e., $GREEN_{green}$ is not expected to go with $BLUE_{red}$). Thus, (high contingency) congruent trials will be faster if preceded by a (high contingency) congruent trial rather than a (low contingency) incongruent trial. Similarly, a (low contingency) incongruent trial will be impaired if preceded by a (high contingency) congruent trial relative to a (low contingency) incongruent trial.[1]

Regardless of what the mechanism is driving the sequential contingency effect, it has been demonstrated by Schmidt and colleagues (2007). Thus, the smaller Stroop effect following (low contingency) incongruent trials relative to (high contingency) congruent trials may be in part a result of a sequential contingency effect rather than a sequential congruency effect.

Further support for the idea that contingency biases contribute to the Gratton effect comes from a study by Mayr and Awh (2009) who varied the proportion of congruent to incongruent trials from 70% to 30% in a six-choice task. Reducing the proportion of congruent trials reduces contingency biases and this manipulation reduced the Gratton effect. However, it did not explain the whole effect: a (reduced) Gratton effect was still present, even after deleting stimulus repetitions in the 30% condition. We do note, however, that 30% congruent items in a six-choice task is still well above chance (16.7%), thus not eliminating all contingency biases. Some studies do present congruent trials no more often than expected by chance, particularly in two-choice tasks (e.g., Davelaar & Stevens, 2009). However, these studies do not control for stimulus

bindings (and cannot do so with a two-choice task). Nieuwenhuis and colleagues (2006) were able to control for response repetitions, however, and this eliminated the Gratton effect in their contingency-unbiased two-choice experiments. Although they were unable to control for partial stimulus repetitions due to the two-choice nature of the tasks, their results are encouraging for the idea that the Gratton effect is due to sequential confounds rather than conflict adaptation.

The Binding Account

We use the term *binding account* to refer to the idea that the Gratton effect is actually due to sequential confounds such as binding effects and contingencies. It has already been demonstrated that both stimulus bindings and contingencies can independently inflate the size of the Gratton effect. Thus, for instance, if one controls for stimulus repetitions, but uses a high proportion of congruent trials, then one cannot know whether the remaining effect is due to conflict adaptation or to contingency biases. In this paper, we report two experiments in which multiple sequential confounds were controlled for simultaneously.

An overview of the literature suggests that most Gratton experiments are confounded by either stimulus binding effects (e.g., Akçay & Hazeltine, 2007, 2008; Davelaar & Stevens, 2009; Egner, Delano, & Hirsch, 2007; Funes, Lupiáñez, & Humphreys, 2010b; Kerns et al., 2004; Notebaert et al., 2006; Ullsperger, Bylsma, & Botvinick, 2005, Experiment 1; Wendt, Kluwe, & Peters, 2006) or contingency biases (e.g., Akçay & Hazeltine, 2007; Mayr & Awh, 2009; Ullsperger et al., 2005, Experiment 2; Verbruggen et al., 2006). Contingency biases are less common in the (typically two-choice) flanker tasks, but stimulus binding effects are much more difficult to control for in these two-choice flanker tasks, for reasons we will discuss later. Stimulus binding trims are often completed in Stroop and Simon experiments but are often incomplete (e.g., Akçay & Hazeltine, 2007, 2008, controlled for stimulus and response repetitions in their Simon experiments, but not for stimulus location to response location

repetitions, or vice versa).

Only one study that we are aware of has effectively controlled for binding effects and contingencies. In experiments reported by Freitas and colleagues (2007) participants performed two two-choice tasks (e.g., a colour-word Stroop and arrow flanker Stroop) that could randomly alternate from trial to trial. Thus, congruency could be manipulated from one trial to the next without repeating any stimuli. There were also no contingency biases. Freitas and colleagues did observe Gratton effects under these conditions. However, this finding is inconsistent with other similar reports showing that the Gratton effect is completely eliminated when the task (or type of interference; i.e., colour-word Stroop or arrow flanker Stroop) on the current trial is different from the task on the previous trial (e.g., Egner et al., 2007; Funes et al., 2010a, 2010b; Wendt et al., 2006). For instance, Wendt and colleagues found that flanker congruency on one trial did not modulate the Simon effect on the following trial and, similarly, that Simon congruency on one trial did not modulate the flanker congruency effect on the following trial. Furthermore, there are some caveats with the task switching approach of Frietas and colleagues. The critical conditions they used not only varied whether the previous trial was congruent or incongruent, but also included a task switch. It could be the case that a task switch is easier following a congruent trial relative to an incongruent trial, leading to quicker task reconfiguration and a larger Stroop effect after congruent relative to incongruent trials (i.e., a Gratton effect). This is not quite the same as the conflict adaptation idea that the conflict itself causes a reduction of attention to the word. A related caveat will be noted below when we introduce the concept of congruency task switches.

In our experiments, we adopted a different approach than that of Freitas and colleagues (2007). In order to completely control for both contingency and stimulus binding confounds, two conditions must be met. Condition 1 is that *all stimulus words must be presented equally often in all colours*. This approach eliminates any impact of contingency biases. Condition 2 is that *all*

responses on trials with word-word, colour-colour, word-colour, and colour-word repetitions

must be removed from the analysis. In this way, stimulus binding effects can no longer produce a

Gratton effect. In order to meet this condition, the task must be four-choice or greater. In two-

and three-choice Stroop tasks it is impossible to delete all types of stimulus repetitions. For

instance, in a three-choice task it is impossible to have an incongruent trial followed by an

incongruent trial without repeating one of the stimulus dimensions. For instance, if $BLUE_{red}$ is

presented on trial $n - 1$, then to make another incongruent trial on trial n one can use the third

colour (e.g., green) as either the colour or the word, but blue or red must be used as the other

stimulus dimension (because there are only three colours in a three-choice task).

In the first of our two experiments, each of four colour words was presented equally often

in each of four colours, thus preventing unwanted contingency learning biases (Condition 1).

Because the task is four-choice, it is possible to get observations for all four congruency by $n - 1$

congruency conditions from trials without word-word, colour-colour, word-colour, or colour-

word stimulus repetitions (Condition 2). As illustrated in Table 1, the manipulation produces 15

different trial types. The first goal of the experiment is to assess Gratton effects before and after

removing repetition trials. For this, Trial Types 1, 3, 6, and 9 can be used to assess Gratton effects

independent of any sequential confounds (see Table 1).

(Table 1 about here)

Congruency Switch Costs

In our experiments, we consider for the first time a third possible source of confounding

that could also contribute to the appearance of a Gratton effect. This third source involves

congruency switch costs and will be referred to as the *switch hypothesis.* The switch hypothesis

posits that the processing and memory encoding of incongruent and congruent trials procedes

somewhat differently. On incongruent trials (e.g., $GREEN_{blue}$), two response codes are generated,

one by the word (green key) and one by the colour (blue key). Thus, the cognitive system must

distinguish between two potential responses and bind one potential response to the word and the

other to the colour. In contrast, on congruent trials (e.g., BLUE$_{blue}$) one response code is

generated by both the word and the colour (blue key). Thus, the cognitive system does not need

to distinguish between two potential responses and the single potential response is bound to both

the colour and the word. In addition, the timing with which stimulus information is available to

the cognitive system is different, due to the conflict occurring on incongruent, but not congruent

trials. Our proposal is that the procedures that the cognitive system must engage in while

processing stimuli and binding information into trial memories are slightly different on congruent

and incongruent trials, thus requiring some reconfiguration on congruency switches (i.e.,

incongruent trials followed by congruent trials and congruent trials followed by incongruent

trials) relative to trials where congruency stays the same (i.e., congruent trials followed by

congruent trials and incongruent trials followed by incongruent trials). This recalibration, we

propose, may sometimes come at a cost, analogous to the performance decrements observed

when a *task* switch occurs (Jersild, 1927; see Monsell, 2003, for a review). Note that this is very

different from detecting conflict and adapting attention (i.e., as per the conflict adaptation

account).

      Congruency switch costs could affect the results in several possible ways. Experiencing a

congruency switch could slow processing (leading to a Gratton effect in response times) and/or it

could increase errors (leading to a Gratton effect in error rates). Either way, the Stroop effect

would be larger on trials following a congruent trial, because there would be a switch cost

impairing incongruent trials, thus increasing the difference between congruent and incongruent

trials. In contrast, the Stroop effect would be smaller on trials following incongruent trials,

because there would be a switch cost impairing congruent trials, thus decreasing the difference

between congruent and incongruent trials.[2] Thus, congruency switch costs will produce a Gratton effect.

Our primary research goal, however, is to assess the validity of the conflict adaptation account of Gratton effects. Therefore, rather than trying to demonstrate the existence of congruency switch effects, our main aim is to determine whether any Gratton effects that remain after trimming stimulus repetitions are due to congruency switch costs or to true conflict adaptation. The conflict adaptation account claims that the change in the size of the contingency effect is due to changes in attention to the word. Given that the Stroop effect is almost exclusively an interference phenomenon (e.g., see MacLeod, 1991, for a review), one should therefore expect that all (or at least most) of the change in the size of the Stroop effect should occur in the incongruent condition. Congruent trials should be largely unaffected due to the fact that fact facilitation for congruent trials is, at best, very minimal.

In contrast, the switch hypothesis proposes performance costs for incongruent trials preceded by congruent trials and (more importantly) congruent trials preceded by incongruent trials. Thus, congruent trials *should* be affected according to the switch hypothesis. Furthermore, analysing congruency as a function of switch rather than $n-1$ congruency should lead to roughly additive effects of congruency and switch (for a similar argument in the proportion congruency literature regarding contingency and congruency, see Schmidt & Besner, 2008). Specifically, congruent trials preceded by an incongruent trial (switch) should be impaired relative to congruent trials preceded by a congruent trial (repetition) and incongruent trials preceded by a congruent trial (switch) should be impaired relative to incongruent trials preceded by an incongruent trial (repetition). That is, there should be slower reaction times and/or a larger number of errors for both congruent and incongruent trials in the switch condition, thus not changing the difference between these two conditions and making this difference roughly the

same size as in the repetition condition. A visual inspection of the results of Freitas and

colleagues (2007), where a Gratton effect was observed after controlling for contingency and

binding biases, seems consistent with this pattern. Note that such a pattern is not consistent with

the conflict adaptation account, because congruent trials should not be affected as much as

incongruent trials by a change in attention to words.

Additionally, if a Gratton effect is observed in errors after the stimulus repetition trims,

then an analysis of the *type* of errors participants make can help us distinguish between conflict

adaptation and congruency switch costs. According to the conflict adaptation account more

attention is given to the word following a congruent relative to an incongruent trial. This should

mean that participants are more prone to produce *word reading errors,* where the participant

produces the response associated with the word rather than the response associated with the

colour (e.g., pressing the green key to the stimulus GREEN$_{\text{blue}}$).[3] The second type of errors are

random errors, that is, where participants press a key at random (often a response other than the

correct response or the response associated with the word). Such errors suggest that the

participant is simply not attending to the task or is stuck coming up with a response and randomly

presses one of the available response buttons. Increased attention to the word should only

produce more word reading errors and not more random errors. In contrast, the switch hypothesis

does not predict an increase in word reading errors after congruent relative to incongruent trials,

but rather predicts an increase in random errors on switch trials when the system is stuck because

of a congruency switch.

Experiment 1

Method

Participants. Twenty-three Ghent University undergraduates participated in exchange for

course credit.

Apparatus. Participants made their responses with an AZERTY keyboard by pressing the "D" key for blue, the "F" key for green, the "J" key for yellow, and the "K" key for red. Stimulus and response timing were controlled by E-Prime (Psychology Software Tools, 2002).

Design. Stimuli were presented on a black screen and consisted of four distracting Dutch colour words (BLAUW [blue], GROEN [green], GEEL [yellow], and ROOD [red]) printed in the same four colours (blue, green, yellow, and red), for a total of 16 unique stimuli. Each word was presented equally often in each colour. Each participant saw 1000 stimuli, which were selected at random *with* replacement (this was to avoid end-of-block learning effects; see Boyer, Destrebecqz, & Cleeremans, 2005; Lee, 1997). Words were presented in lowercase, bold, 18 pt Bookman Old Style font. The RGB values for the colours were 60,170,255 (blue), 0,255,0 (green), 255,255,0 (yellow), and 255,0,0 (red).

Procedure. Participants sat approximately 60 cm from the screen. On each trial, they were presented with a white "+" as a fixation for 100 ms, followed by a blank screen for 100 ms, followed by the stimulus for 1500 ms or until a response was made. This was followed by 400 ms of blank screen for correct responses or 400 ms of "XXX" in red for incorrect responses and trials where participants failed to respond.

Results

Mean correct response latencies and error percentages were collected for each participant. The means for each of the 15 unique repetition trial types are presented in Table 1. Gratton effects were first analysed without removing stimulus repetitions and then with colour-colour, word-word, word-colour, and colour-word repetitions removed (Types 1, 3, 6, and 9 in Table 1). The data of non-repetition trials were also analysed for block effects. Finally, the error data were analysed for switch effects. Trials in which participants failed to respond were excluded from all analyses.

Response latencies with repetitions included. We first examined the response latencies with repetition trials included in the analysis. These data are presented in the left panel of Figure 1. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n - 1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,22) = 93.863$, $MSE = 848$, $p < .001$, $\eta_p^2 = .81$, indicating an overall Stroop effect. The main effect for $n - 1$ congruency was not significant, $F(1,22) = .457$, $MSE = 347$, $p = .506$, $\eta_p^2 = .02$. Critically, the congruency by $n - 1$ congruency interaction was significant, $F(1,22) = 6.415$, $MSE = 510$, $p = .019$, $\eta_p^2 = .23$, indicating a larger Stroop effect for trials following a congruent trial (i.e., a Gratton effect). The congruency effect was significant for trials following a congruent trial (congruent: 648 ms; incongruent: 718 ms), $t(22) = 7.372$, $SE_{diff} = 9.6$, $p < .001$, $\eta_p^2 = .71$, and for trials following an incongruent trial (congruent: 662 ms; incongruent: 709 ms), $t(22) = 9.202$, $SE_{diff} = 5.1$, $p < .001$, $\eta_p^2 = .79$.

(Figure 1 about here)

Response latencies with repetitions excluded. The next analysis took into account only the response latencies on alternation trials (i.e., where no stimulus dimensions repeated). These data are presented in the right panel of Figure 1. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n - 1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,22) = 78.437$, $MSE = 2065$, $p < .001$, $\eta_p^2 = .78$, indicating an overall Stroop effect. The main effect for $n - 1$ congruency was not significant, $F(1,22) = .026$, $MSE = 737$, $p = .874$, $\eta_p^2 < .01$. Critically, the congruency by $n - 1$ congruency interaction was *not* significant, $F(1,22) = .009$, $MSE = 663$, $p = .926$, $\eta_p^2 < .0005$, indicating that the Stroop effect was the same size for trials following congruent and incongruent trials (i.e., no

Gratton effect). The effect size (η_p^2) of this interaction was quite small and the test had medium

power (.56) to detect an interaction of the size that was observed in the full set of trials. Further,

when these trimmed response latencies were compared with the repetition trials that were deleted

by adding repetition as a factor (non-repetition vs. repetition), a significant three-way interaction

between congruency, $n - 1$ congruency, and repetition emerged, $F(1,22) = 39.576$, $MSE = 564$, p

$= .001$, $\eta_p^2 = .64$, demonstrating a significant reduction in the size of the Gratton effect by

removing repetitions. Thus, discarding repetition trials appeared to have eliminated the Gratton

effect. As no effect remained, a switch analysis on response times was not conducted. The

congruency effect was significant for trials following a congruent trial (congruent: 702 ms;

incongruent: 787 ms), $t(22) = 7.856$, $SE_{diff} = 10.7$, $p < .001$, $\eta_p^2 = .74$, and for trials following an

incongruent trial (congruent: 702 ms; incongruent: 785 ms), $t(22) = 7.559$, $SE_{diff} = 10.0$, $p < .001$,

$\eta_p^2 = .72$.

Blocked response latencies. As results from Mayr and Awh (2009) suggest that conflict

adaptation effects might be more likely early in the task, the data with repetitions excluded was

then split into four blocks of 250 trials each. These data are presented in Table 2. Splitting the

data into smaller blocks, in combination with the deletion of stimulus repetitions, greatly reduces

the number of observations per cell (making the data noisier). Indeed, one participant had to be

deleted due to not having an observation in every cell. An ANOVA with factors of block (1-4),

congruency (congruent vs. incongruent), and $n - 1$ congruency (congruent vs. incongruent) did

not reveal a critical three-way interaction, $F(3,63) = .472$, $MSE = 1483$, $p = .703$, $\eta_p^2 = .02$,

indicating no significant differences between the size of the (null) Gratton effect across blocks.

Furthermore, an ANOVA for the first block alone with factors of congruency (congruent vs.

incongruent) and $n - 1$ congruency (congruent vs. incongruent) did not reveal a significant

interaction, $F(1,21) = .518$, $MSE = 2411$, $p = .480$, $\eta_p^2 = .02$. Indeed, the difference was in the incorrect direction for a Gratton effect.

(Table 2 about here)

Errors with repetitions included. The percentage errors with repetitions included are presented in the left panel of Figure 2. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n-1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,22) = 17.894$, $MSE = 35$, $p < .001$, $\eta_p^2 = .45$, indicating an overall Stroop effect. The main effect for $n-1$ congruency was not significant, $F(1,22) = .841$, $MSE = 7$, $p = .369$, $\eta_p^2 = .04$. Critically, the congruency by $n-1$ congruency interaction was significant, $F(1,22) = 15.480$, $MSE = 9$, $p < .001$, $\eta_p^2 = .41$, indicating a larger Stroop effect for trials following a congruent trial (i.e., a Gratton effect). The congruency effect was significant for trials following a congruent trial (congruent: 7.6%; incongruent: 14.9%), $t(22) = 4.496$, $SE_{diff} = 1.7$, $p < .001$, $\eta_p^2 = .48$, and for trials following an incongruent trial (congruent: 8.2%; incongruent: 12.0%), $t(22) = 2.925$, $SE_{diff} = 1.0$, $p = .008$, $\eta_p^2 = .28$.

(Figure 2 about here)

Errors with repetitions excluded. The percentage errors for alternation trials (i.e., with all stimulus repetitions excluded) are presented in the right panel of Figure 2. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n-1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,22) = 18.225$, $MSE = 48$, $p < .001$, $\eta_p^2 = .45$, indicating an overall Stroop effect. The main effect for $n-1$ congruency was not significant, $F(1,22) = .106$, $MSE = 15$, $p = .748$, $\eta_p^2 < .01$. Inconsistent with the response time data, the congruency by $n-1$ congruency interaction was significant, $F(1,22) = 8.181$, $MSE = 13$,

$p = .009$, $\eta_p^2 = .27$, indicating a larger Stroop effect for trials following a congruent trial (i.e., a

Gratton effect). Thus, while removing stimulus repetitions eliminated the Gratton effect in the

response times, it did not eliminate the Gratton effect in the errors (though the switch analysis

will provide an explanation for this remaining effect). The congruency effect was significant for

trials following a congruent trial (congruent: 8.3%; incongruent: 16.7%), $t(22) = 4.537$, $SE_{diff} =$

1.8, $p < .001$, $\eta_p^2 = .48$, and for trials following an incongruent trial (congruent: 10.2%;

incongruent: 14.2%), $t(22) = 2.863$, $SE_{diff} = 1.4$, $p = .009$, $\eta_p^2 = .27$.

Blocked errors. Like the response latencies, the error data with repetitions excluded was

then split into four blocks of 250 trials each. This data is presented in Table 3. The same

participant had to be deleted due to not having an observation in every cell. An ANOVA with

factors of block (1-4), congruency (congruent vs. incongruent), and $n - 1$ congruency (congruent

vs. incongruent) did not reveal a critical three-way interaction, $F(3,63) = .793$, $MSE = 49$, $p =$

.502, $\eta_p^2 = .04$, indicating no significant differences between the size of the Gratton effect across

blocks.

(Table 3 about here)

Word reading errors. For each participant, word reading errors for incongruent trials

were calculated as the percent of errors for the incongruent response that exceeds the percent of

errors to other incorrect responses. Word reading errors accounted for a large portion of the

congruency effect. Participants made 4.0% word reading errors to incongruent trials following a

congruent trial and 3.4% word reading errors to incongruent trials following an incongruent trial.

This 0.6% difference was not significant, $t(22) = .625$, $SE_{diff} = 1.0$, $p = .538$, $\eta_p^2 = .02$, consistent

with the switch hypothesis. This test had high power (.80) to detect an effect as small as 2.9% and

very high power (>.99) to detect an effect as small as the Gratton effect observed in the error data

with repetitions included.

Random errors. Random errors are what remain after removing word reading errors. The

data for random errors are presented in Figure 3. An ANOVA with the factors of switch type

(repetition vs. switch) and congruency (congruent vs. incongruent) revealed a significant effect of

switch type, $F(1,22) = 4.495$, $MSE = 18$, $p = .046$, $\eta_p^2 = .17$, indicating more errors overall for

switch trials. The main effect of congruency was marginal, $F(1,22) = 3.847$, $MSE = 37$, $p = .063$,

$\eta_p^2 = .15$, demonstrating a small impact of random errors on the congruency effect (i.e., in

addition word reading errors). Critically, the interaction between switch type and congruency was

not significant, $F(1,22) = .002$, $MSE = 19$, $p = .962$, $\eta_p^2 < .0001$, again consistent with the switch

hypothesis. The effect size (η_p^2) was very small and power was high (.80) to detect an interaction

as small as 5.3%.

(Figure 3 about here)

Discussion

Experiment 1 replicated the basic Gratton effect in response times and error rates.

However, by using stimuli that were not contingency biased and removing trials containing

stimulus repetitions the Gratton effect was eliminated in the response times, even in the first

block (cf., Mayr & Awh, 2009). These results support the binding account by showing that the

Gratton effect is fully explained by stimulus binding and contingency confounds. Indeed, the

means for congruent and incongruent trials in the two $n - 1$ congruency conditions are essentially

identical. No evidence for conflict adaptation was found in the response latencies.

A relatively large Gratton effect did remain in the error data after removing stimulus

repetitions. Without further analysis, this effect would be consistent with the conflict adaptation

account. However, further analyses demonstrated that this remaining effect was due to

congruency switch costs and not conflict adaptation. Specifically, word reading errors were not more likely following a congruent than an incongruent trial, in contrast to the prediction of increased errors by the conflict adaptation account. Instead, the error Gratton effect was due to a greater number of random key press errors following a congruency switch (i.e., a congruent trial followed by an incongruent trial or an incongruent trial followed by a congruent trial). The conflict adaptation account was therefore unable to explain any of the data in Experiment 1. These results instead provide tentative support for the idea that congruency switch costs can contribute to the Gratton effect. No switch costs were found for response times.

<div align="center">

Experiment 2

</div>

Experiment 2 was conceptually identical to Experiment 1, but was a flanker task rather than a colour-word Stroop task. In the Flanker task (Eriksen & Eriksen, 1974), a centrally-located target letter is presented with distracting letters flanking it to the left and right (e.g., FFJFF, where "J" is the target and the "F"s are distracters). The flankers match the target on congruent trials (e.g., JJJJJ) and mismatch on incongruent trials (e.g., FFJFF). Similar to a colour-word Stroop task, participants respond to the identity of the target with a key press. This experiment served as a replication of Experiment 1.

<div align="center">

Method

</div>

Participants

Twenty-four Ghent University undergraduates participated in exchange for course credit.

Apparatus

The apparatus for Experiment 2 was identical to that of Experiment 1, except participants pressed the "D" key for D, the "F" key for F, the "J" key for J, and the "K" key for K.

Design and Procedure

The design and procedure of Experiment 2 were identical to those of Experiment 1 with a

few exceptions. Stimuli were strings of five capital letters presented in white, which consisted of

one centrally-located target letter (D, F, J, or K) and a distracting letter (D, F, J, or K) presented

twice to the left and the right of the target (e.g., KKFKK), for a total of 16 unique stimuli. Each

target letter was presented equally often with each distracter letter.

Results

Mean correct response latencies and error percentages were collected for each participant.

The means for each of the 15 unique repetition trial types are presented in Table 4. Gratton

effects were first assessed without removing trials with repetitions and second with target-target,

flanker-flanker, flanker-target, and target-flanker repetitions removed (Types 1, 3, 6, and 9 in

Table 4). The data of non-repetition trials were also analysed for block effects. Trials in which

participants failed to respond were excluded from all analyses.

(Table 4 about here)

Response latencies with repetitions included. We first examined the response latencies

with repetition trials included in the analysis. These data are presented in the left panel of Figure

4. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n-1$ congruency

(congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,23) = 130.940$,

$MSE = 266$, $p < .001$, $\eta_p^2 = .85$, indicating an overall Stroop effect. The main effect for $n-1$

congruency was significant, $F(1,23) = 4.522$, $MSE = 292$, $p = .044$, $\eta_p^2 = .16$. Critically, the

congruency by $n-1$ congruency interaction was significant, $F(1,23) = 7.624$, $MSE = 222$, $p =$

$.011$, $\eta_p^2 = .25$, indicating a larger Stroop effect for trials following a congruent trial (i.e., a

Gratton effect). The congruency effect was significant for trials following a congruent trial

(congruent: 590 ms; incongruent: 636 ms), $t(23) = 8.017$, $SE_{diff} = 5.8$, $p < .001$, $\eta_p^2 = .74$, and for

trials following an incongruent trial (congruent: 606 ms; incongruent: 635 ms), $t(22) = 11.178$,

$SE_{diff} = 2.7$, $p < .001$, $\eta_p^2 = .84$.

(Figure 4 about here)

Response latencies with repetitions excluded. The next analysis took into account only the response latencies on alternation trials (i.e., where no stimulus dimensions repeated). These data are presented in the right panel of Figure 4. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n - 1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,23) = 82.776$, $MSE = 320$, $p < .001$, $\eta_p^2 = .78$, indicating an overall Stroop effect. The main effect for $n - 1$ congruency was not significant, $F(1,23) = .260$, $MSE = 640$, $p = .615$, $\eta_p^2 = .01$. Critically, the congruency by $n - 1$ congruency interaction was *not* significant, $F(1,23) = .890$, $MSE = 663$, $p = .375$, $\eta_p^2 = .04$, indicating that the Stroop effect was the same size for trials following congruent and incongruent trials (i.e., no Gratton effect). The effect size (η_p^2) of this interaction was small and the test had medium power (.53) to detect an interaction of the size that was observed in the full set of trials. Further, when these trimmed response latencies were compared with the repetition trials that were deleted by adding repetition as a factor (non-repetition vs. repetition), a significant three-way interaction between congruency, $n - 1$ congruency, and repetition emerged, $F(1,23) = 25.210$, $MSE = 491$, $p = .001$, $\eta_p^2 = .52$, demonstrating a significant reduction in the size of the Gratton effect by removing repetitions. Thus, discarding repetition trials again eliminated the Gratton effect. The congruency effect was significant for trials following a congruent trial (congruent: 623 ms; incongruent: 660 ms), $t(23) = 5.643$, $SE_{diff} = 6.5$, $p < .001$, $\eta_p^2 = .58$, and for trials following an incongruent trial (congruent: 624 ms; incongruent: 653 ms), $t(23) = 7.595$, $SE_{diff} = 3.9$, $p < .001$, $\eta_p^2 = .71$.

Blocked response latencies. As with Experiment 1, the data with repetitions excluded was then split into four blocks of 250 trials each. These data are presented in Table 5. An ANOVA with factors of block (1-4), congruency (congruent vs. incongruent), and $n-1$ congruency (congruent vs. incongruent) did not reveal a critical three-way interaction, $F(3,69) = .096$, $MSE = 1096$, $p = .962$, $\eta_p^2 < .01$, indicating no significant differences between the size of the (null) Gratton effect across blocks. Furthermore, an ANOVA for the first block alone with factors of congruency (congruent vs. incongruent) and $n-1$ congruency (congruent vs. incongruent) did not reveal a significant interaction, $F(1,23) = .184$, $MSE = 1551$, $p = .672$, $\eta_p^2 < .01$. Indeed, the interaction was numerically in the incorrect direction for a Gratton effect.

(Table 5 about here)

Errors with repetitions included. The error effects (along with the overall error rate) in Experiment 2 were generally much smaller than those observed in Experiment 1. The percentage errors with repetitions included are presented in the left panel of Figure 5. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n-1$ congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F(1,23) = 6.979$, $MSE = 10$, $p = .015$, $\eta_p^2 = .23$, indicating an overall Stroop effect. The main effect for $n-1$ congruency was not significant, $F(1,23) = .760$, $MSE = 3$, $p = .392$, $\eta_p^2 = .03$. In contrast to the results of Experiment 1, the congruency by $n-1$ congruency interaction was not significant in the untrimmed data, $F(1,23) = .014$, $MSE = 7$, $p = .906$, $\eta_p^2 < .001$, indicating no difference in the size of the Stroop effect for trials following a congruent trial (i.e., no Gratton effect). The congruency effect was not significant for trials following a congruent trial (congruent: 6.5%; incongruent: 8.3%), $t(23) = 1.688$, $SE_{diff} = 1.1$, $p = .105$, $\eta_p^2 = .11$, and was significant for trials following an incongruent trial

(congruent: 6.3%; incongruent: 8.0%), $t(23) = 3.162$, $SE_{diff} = .5$, $p = .004$, $\eta_p^2 = .30$.

(Figure 5 about here)

Errors with repetitions excluded. The percentage errors for alternation trials (i.e., with all stimulus repetitions excluded) are presented in the right panel of Figure 5. An ANOVA with the factors of congruency (congruent vs. incongruent) and $n - 1$ congruency (congruent vs. incongruent) was conducted. The main effect of congruency was not significant, $F(1,23) = 1.417$, $MSE = 19$, $p = .246$, $\eta_p^2 = .06$, nor was the main effect for $n - 1$ congruency, $F(1,23) = 2.650$, $MSE = 9$, $p = .117$, $\eta_p^2 = .10$. Critically, the congruency by $n - 1$ congruency interaction was not significant, $F(1,23) = .089$, $MSE = 14$, $p = .768$, $\eta_p^2 < .004$, indicating no difference in the size of the Stroop effect for trials following a congruent trial (i.e., no Gratton effect). The effect size for this comparison (η_p^2) was quite small and the test had high power (.80) to detect an effect as small as 4.5%. Indeed, the numerical difference was in the incorrect direction for a Gratton effect. The congruency effect was not significant for trials following a congruent trial (congruent: 8.8%; incongruent: 9.6%), $t(23) = .546$, $SE_{diff} = 1.5$, $p = .590$, $\eta_p^2 = .01$, but was marginal for trials following an incongruent trial (congruent: 7.5%; incongruent: 8.9%), $t(23) = 1.939$, $SE_{diff} = .7$, $p = .065$, $\eta_p^2 = .14$.

Blocked errors. Like the response latencies, the error data with repetitions excluded was then split into four blocks of 250 trials each. This data is presented in Table 6. An ANOVA with factors of block (1-4), congruency (congruent vs. incongruent), and $n - 1$ congruency (congruent vs. incongruent) did not reveal a critical three-way interaction, $F(3,69) = 2.020$, $MSE = 44$, $p = .119$, $\eta_p^2 = .08$, indicating no significant differences between the size of the (null) Gratton effect across blocks. Furthermore, an ANOVA for the first block alone with factors of congruency

(congruent vs. incongruent) and $n - 1$ congruency (congruent vs. incongruent) did not reveal a

significant interaction, $F(1,23) = .043$, $MSE = 35$, $p = .838$, $\eta_p^2 < .002$. Again, the effect was

numerically in the incorrect direction for a Gratton effect.

<div align="center">(Table 6 about here)</div>

Discussion

Similar to Experiment 1, Experiment 2 replicated the basic Gratton effect in response

times. However, by using stimuli that were not contingency biased and removing trials containing

stimulus repetitions the Gratton effect was again eliminated, even in the first block. These results

again support the binding account by showing that the Gratton effect is fully explained by

stimulus binding and contingency confounds and again produced no evidence for conflict

adaptation. In contrast to Experiment 1, no Gratton effect in errors was observed in Experiment 2,

even in the untrimmed data. Thus, there was no point in conducting switch analyses on these

data. These data were therefore also unable to provide us another test of the switch hypothesis.

Most critically, however, Experiment 2 again failed to find any support for the conflict adaptation

account of Gratton effects.

<div align="center">**General Discussion**</div>

The results of two experiments provide strong support for an interpretation of the Gratton

effect that does not rely on conflict adaptation processes. The response time data of both the

colour-word Stroop (Experiment 1) and Eriksen flanker (Experiment 2) experiments

demonstrated that if the task is not biased by contingencies and if stimulus repetitions are

removed, then the Gratton effect is eliminated. Although the Gratton effect did remain in the

errors of Experiment 1 (but not Experiment 2) after deleting stimulus repetitions, the switch

analysis of these error data supported the predictions of the switch hypothesis and disconfirmed

the conflict adaptation account. Specifically, the remaining Gratton effect in the errors was due to increased random key press errors following a congruency switch and *not* by an increase in word reading errors following congruent trials. Thus, none of the results reported in the current work were consistent with the conflict adaptation account of Gratton effects.

Indeed, without the switch analysis, the conflicting results for response latencies and errors would seem unusual from the perspective of both the binding account and the conflict adaptation account. Ignoring congruency switch costs as a potential confound, clearly the binding account would have had to predict a null Gratton effect in the errors. However, the conflicting results would not have fitted well with the conflict adaptation account, either. It is not clear how the attentional mechanism proposed by the conflict adaptation account could produce an effect in errors and not response times. If participants are decreasing attention to the word (or increasing attention to the colour) following incongruent trials, then this should certainly lead to a Gratton effect on response times in addition to errors (especially given that the response time Stroop effect is substantially more reliable than the corresponding error effect). Furthermore, decreasing attention to the word following an incongruent (conflict) trial should increase the number of word reading errors on the following trial. This was not observed. Instead, the error Gratton effect was due to greater random key press errors when congruency switched, as predicted by the switch hypothesis.

If the switch analysis were ignored, one may want to argue that observing an effect in errors but not response times is not a problem for the conflict adaptation account. Indeed, although response time effects are generally much more reliable than error effects, it is certainly possible to maximize effects in errors while decreasing effects in response times, for instance, by using a response deadline procedure (e.g., Jacoby, Lindsay, & Hessels, 2003; Lindsay & Jacoby, 1994). However, there was a reliable and sufficiently large (84 ms) main effect of congruency in

the response time data of Experiment 1 with repetitions excluded, demonstrating clearly that response time effects were present, but they were simply not modulated by $n - 1$ congruency. Thus, there was no trade-off between response time and error effects.

Alternatively, one could defend the conflict adaptation account by suggesting that there was a ceiling effect for incongruent trials in the response latency data, thus preventing an increased interference effect following congruent trials in response times. However, this seems both unusual and unlikely given that these trials were not responded to unusually slowly (indeed, faster than some similar reports; e.g., Mayr & Awh, 2009). Further, the switch analysis was inconsistent with the conflict adaptation prediction that the error Gratton effect should be driven by increased word reading errors. From our perspective, the account that best fits the data is a hybrid of the binding account and the switch hypothesis. It must be noted, however, that support for our a priori switch hypothesis is currently limited only to the error data of one of our experiments. More work is of course necessary. Nevertheless, the data support the conclusion that the Gratton effect is merely the by-product of contingency, stimulus binding, and (possibly) congruency switch costs. This contrasts sharply with the conventional view, which touts the Gratton effect as a demonstration of cognitive control.

Conflict Monitoring

The results of this work bear strongly on the conflict monitoring literature. Botvinick and colleagues (2001) presented a computational model that both detects conflict (e.g., on an incongruent trial) and subsequently adapts to this conflict by adjusting attention. The two key pieces of evidence produced for supporting the conflict monitoring model of Botvinick and colleagues are the proportion congruent effect and the Gratton effect. However, Schmidt and Besner (2008; see also, Schmidt, 2010; Schmidt et al., 2007) have called into question whether proportion congruent effects have anything to do with conflict adaptation. Schmidt and Besner

demonstrated that confounding contingencies present in the task completely explain the effect. Schmidt (2010) further developed a computation model that learns contingencies instead of adapting to conflict and can simulate proportion congruent effects (for conflict adaptation competitors, see Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008). Although this is still a very heated area of debate, this work suggests that the proportion congruent effect is driven by learned word-response relationships and not conflict adaptation. While the lead author has argued (often parenthetically) in these papers that Gratton effects, in contrast to proportion congruent effects, are probably due to conflict adaptation, the results of the present paper suggest otherwise. That is, the Gratton effect, too, is fully explained by confounds present in the task, and not by conflict adaptation. If this assertion is true, then this fact has serious implications for the conflict monitoring idea in general.

One purported strength of the conflict monitoring account is that it has been used to account for both behavioural and brain data (e.g., see the original conflict monitoring paper by Botvinick et al., 2001). In particular, the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC) have been implicated in conflict monitoring and adaptation. It is important to highlight, however, that none of the key neuroimaging papers demonstrating a relationship between ACC and/or DLPFC activation and a behavioural effect properly control for all confounds. In particular, every one of these papers either introduces contingency confounds (e.g., Kerns et al., 2004) or fails to control for some or all stimulus binding effects (e.g., Blais & Bunge, 2010).

ACC and DLPFC activation have been described as evidence for conflict adaptation. However, it is equally conceivable that the ACC and DLPFC are responsible for memory consolidation or retrieval processes. Indeed, these areas have been implicated in this respect long before the conflict monitoring model was first proposed (e.g., see a review by Cabeza & Nyberg,

1997). Further, our episodic memory account (Schmidt, 2010) assumes that short-term binding

effects and long-term contingency learning effects are the result of the same memory storage and

retrieval processes, so it stands to reason that both types of biases should be associated with

activation in the same (or similar) regions (see, Nairne, 1996; Öztekin, McElree, Staresina, &

Davachi, 2008, for more on the single-store perspective on memory). The episodic account is also

elegant and parsimonious in that various cognitive results (e.g., the proportion congruent effect

and Gratton effect) are simply an incidental byproduct of memory storage and retrieval processes.

It is not unequivocally clear that one needs to make further assumptions about rapid cognitive

control mechanisms such as the conflict monitoring and conflict adaptation processes suggested

by authors such as Botvinick and colleagues (2001).

   If, however, in contrast to the current results, a Gratton effect can be demonstrated after

all of the confounds highlighted in this paper have been controlled, then it is still necessary for

these controls to be conducted in all future work with the Gratton effect. By failing to control for

these confounds, one can never know whether a given result (e.g., the correlation between the

behavioural effect and ACC/DLPFC activity) is due to conflict adaptation or to one or more of

these confounds.

Conclusions

   The results of the analyses presented in this paper suggest that the Gratton effect, contrary

to popular belief, is not due to conflict adaptation. Instead, sequential task biases such as

contingencies, stimulus bindings, and (possibly) congruency switch costs account for the critical

interaction between congruency and $n − 1$ congruency. The Gratton effect does not therefore

seem to be an index of cognitive control. At a minimum, cognitive control processes certainly do

not seem to account for very much variance in this paradigm. This work, along with related work

from our lab (e.g., Schmidt, 2010; Schmidt & Besner, 2008), has potentially devastating

consequences for theory on conflict monitoring and conflict adaptation. Further research in this

domain is certainly warranted.

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Footnotes

[1] All (low contingency) incongruent items are presented infrequently, so a series of two of them does not violate any sequential trial biases.

[2] Note that an argument similar to this could be forwarded for the sequential *contingency* effect, as well. That is, the sequential contingency effect might be partially (or wholly) due to *contingency* switch costs.

[3] Note, of course, that in a key press task a word reading error is not, strictly speaking, a word "reading" error, but the idea is the same: participants output the response associated with the distracting word rather than the response associated with the target colour.

Table 1. Experiment 1 trial type examples with response times and errors

Trial Type	W-W	C-C	W-C	C-W	Response Time	Error Rate
Congruent – Congruent						
(1) **BLUE$_{blue}$ → RED$_{red}$**					*702 ms*	*8.3%*
(2) BLUE$_{blue}$ → BLUE$_{blue}$	x	x	x	x	494 ms	3.8%
Congruent – Incongruent						
(3) **BLUE$_{blue}$ → RED$_{green}$**					*787 ms*	*16.7%*
(4) BLUE$_{blue}$ → BLUE$_{red}$	x			x	749 ms	16.0%
(5) BLUE$_{blue}$ → RED$_{blue}$		x	x		570 ms	10.7%
Incongruent – Congruent						
(6) **RED$_{blue}$ → GREEN$_{green}$**					*702 ms*	*10.2%*
(7) RED$_{blue}$ → RED$_{red}$	x		x		696 ms	11.9%
(8) RED$_{blue}$ → BLUE$_{blue}$		x		x	559 ms	4.4%
Incongruent – Incongruent						
(9) **RED$_{blue}$ → GREEN$_{yellow}$**					*785 ms*	*14.2%*
(10) RED$_{blue}$ → RED$_{green}$	x				754 ms	13.5%
(11) RED$_{blue}$ → GREEN$_{blue}$		x			571 ms	8.6%
(12) RED$_{blue}$ → RED$_{blue}$	x	x			520 ms	5.2%
(13) RED$_{blue}$ → GREEN$_{red}$			x		773 ms	14.5%
(14) RED$_{blue}$ → BLUE$_{green}$				x	755 ms	12.1%
(15) RED$_{blue}$ → BLUE$_{red}$			x	x	759 ms	12.7%

*W-W = word-word; C-C = colour-colour; W-C = word-colour; C-W = colour-word

Table 2. Experiment 1 response times by trial type and block

Trial Type	Block			
	1-250	251-500	501-725	726-1000
Congruent-Congruent	732 ms	677 ms	687 ms	700 ms
Congruent-Incongruent	789 ms	783 ms	771 ms	759 ms
Incongruent-Congruent	703 ms	693 ms	695 ms	685 ms
Incongruent-Incongruent	776 ms	778 ms	785 ms	755 ms
Gratton Effect	*-15 ms*	*21 ms*	*-5 ms*	*-11 ms*

Table 3. Experiment 1 errors by trial type and block

Trial Type	Block			
	1-250	251-500	501-725	726-1000
Congruent-Congruent	8.7%	8.0%	5.9%	9.6%
Congruent-Incongruent	18.1%	17.0%	15.6%	15.3%
Incongruent-Congruent	9.0%	8.9%	9.6%	13.3%
Incongruent-Incongruent	16.0%	11.6%	11.0%	15.5%
Gratton Effect	*2.4%*	*6.2%*	*8.3%*	*3.5%*

Table 4. Experiment 2 trial type examples with response times and errors

Trial Type	F-F	T-T	F-T	T-F	Response Time	Error Rate
	Repetition Type*					
Congruent – Congruent						
(1) **DDDDD → FFFFF**					***623 ms***	***8.8%***
(2) DDDDD → DDDDD	x	x	x	x	498 ms	.3%
Congruent – Incongruent						
(3) **DDDDD → FFJFF**					***660 ms***	***9.6%***
(4) DDDDD → DDFDD	x			x	661 ms	10.9%
(5) DDDDD → FFDFF		x	x		572 ms	3.1%
Incongruent – Congruent						
(6) **FFDFF → JJJJJ**					***624 ms***	***7.6%***
(7) FFDFF → FFFFF	x		x		623 ms	7.8%
(8) FFDFF → DDDDD		x		x	550 ms	1.8%
Incongruent – Incongruent						
(9) **FFDFF → JJKJJ**					***653 ms***	***8.9%***
(10) FFDFF → FFJFF	x				661 ms	9.5%
(11) FFDFF → JJDJJ		x			575 ms	3.2%
(12) FFDFF → FFDFF	x	x			545 ms	3.6%
(13) FFDFF → JJFJJ			x		662 ms	10.3%
(14) FFDFF → DDJDD				x	665 ms	9.3%
(15) FFDFF → DDFDD			x	x	665 ms	10.4%

*F-F = flanker-flanker; T-T = target-target; F-T = flanker-target; T-F = target-flanker

Table 5. Experiment 2 response times by trial type and block

Trial Type	Block			
	1-250	251-500	501-725	726-1000
Congruent-Congruent	631 ms	636 ms	619 ms	595 ms
Congruent-Incongruent	671 ms	671 ms	662 ms	632 ms
Incongruent-Congruent	644 ms	634 ms	617 ms	601 ms
Incongruent-Incongruent	677 ms	655 ms	653 ms	634 ms
Gratton Effect	*-7 ms*	*14 ms*	*7 ms*	*4 ms*

Table 6. Experiment 2 errors by trial type and block

Trial Type	Block			
	1-250	251-500	501-725	726-1000
Congruent-Congruent	6.4%	4.2%	13.5%	10.8%
Congruent-Incongruent	7.4%	9.1%	10.5%	11.6%
Incongruent-Congruent	6.9%	7.0%	10.6%	5.7%
Incongruent-Incongruent	8.4%	7.0%	11.7%	8.3%
Gratton Effect	*-.5%*	*5.0%*	*-4.1%*	*-1.8%*

Figures

Figure 1. Experiment 1 response latencies and standard error bars for congruency and $n - 1$ congruency. Data with repetitions included on left; data with repetitions excluded on right.

Figure 2. Experiment 1 percentage errors and standard error bars for congruency and $n - 1$ congruency. Data with repetitions included on left; data with repetitions excluded on right.

Figure 3. Experiment 1 percentage errors and standard error bars for congruency and switch on random errors.

Figure 4. Experiment 2 response latencies and standard error bars for congruency and $n - 1$ congruency. Data with repetitions included on left; data with repetitions excluded on right.

Figure 5. Experiment 2 percentage errors and standard error bars for congruency and $n - 1$ congruency. Data with repetitions included on left; data with repetitions excluded on right.