

Attentional control adjustments in Eriksen and Stroop task performance can be independent of response conflict

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In the Eriksen flanker and colour-word Stroop tasks, the response time (RT) difference between incongruent and congruent trials is smaller following incongruent trials than following congruent trials: the “Gratton effect” (Gratton, Coles, & Donchin, 1992). According to the prevailing conflict-monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001), the Gratton effect reflects attentional control adjustment following response conflict on incongruent trials. However, because previous studies compared incongruent and congruent trials, it remains unclear to what extent the Gratton effect is driven by incongruent rather than congruent trials. To resolve this issue, we included neutral trials in addition to incongruent and congruent trials in the Eriksen (Experiment 1) and Stroop (Experiment 2) tasks. Participants responded manually and vocally in both tasks. Moreover, we assessed responding to Stroop stimuli that were preceded by neutral cues or by incongruent- or congruent-predicting cues (Experiment 3). In all three experiments, the RT difference between incongruent and congruent trials was larger for postcongruent trials than for postincongruent and postneutral trials. These findings suggest that control adjustments can be independent of response conflict, challenging conflict-monitoring theory.

Keywords: Attention; Conflict; Control adjustment; Expectation.

The human attention system seems to employ various strategies in filtering information from the environment (cf. Broadbent, 1958, 1971). A growing number of studies suggest that humans can switch dynamically between attention strategies if needed (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Cohen, Botvinick, & Carter, 2000; Gratton, Coles, & Donchin, 1992; Logan, 1985). For example, imagine that you

have to respond to the central letter in a letter string. Perhaps standard you would focus your attention in the middle of the string. But if on most trials, the other letters in the string are identical to the target, you could modify your strategy by widening your attention such that the other letters—which are not competing for your response—are also processed to some extent. Because the flankers activate the same response

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as the central letter, the average response time (RT) across trials is reduced.

In the last decade, researchers have made considerable progress in unravelling the various processes involved in this ability of the human attention system to dynamically adjust itself to optimize performance. This ability is often referred to as *attentional control* (e.g., Posner & Raichle, 1994; Roelofs, 2003). If we want to understand how people make strategic adjustments based on their own behaviour and on the specific type of information available at a particular time, it is crucial that we understand the different functions underlying attentional control in detail.

Much recent research of attentional control adjustments has been driven by the observation that the RT difference between incongruent and congruent trials is smaller following an incongruent trial than following a congruent trial, as observed in a seminal study by Gratton et al. (1992). Subsequent research referred to this finding as the “Gratton effect” (e.g., Botvinick et al., 2001; Verbruggen, Notebaert, Liefoghe, & Vandierendonck, 2006). According to the prevailing account in the literature (e.g., Botvinick et al., 2001), the Gratton effect indicates attentional control adjustments following response conflict on incongruent trials. However, because previous studies compared incongruent and congruent trials, it has remained unclear to what extent the adjustments are driven by incongruent rather than congruent trials. The aim of the research reported in the present article was to examine this issue. We start by briefly reviewing the burgeoning literature on the Gratton effect and the different underlying RT patterns that give rise to the effect. Next, we present the results of three new RT experiments in which we employed neutral stimuli (Experiments 1 and 2) or cues (Experiment 3) to examine the role of response conflict. Finally, we discuss the consequences of our results for the conflict-adaptation view, and we present the results of computer simulations demonstrating the utility of a new two-factor account of the Gratton effect and the various underlying RT patterns in the literature and the present experiments.

Review of the Gratton effect and underlying RT patterns

The Gratton effect is studied by using tasks that elicit conflict in responding, like the flanker task of Eriksen and Eriksen (1974). In the original version of this task, a string of seven characters was presented briefly on a screen, and participants had to manually indicate the identity of the central character (H or S) as quickly and accurately as possible. The six flankers were either identical to the target (a congruent trial, e.g., HHHHHHH) or different from the target and associated with the alternative response (an incongruent trial, e.g., SSSHSSS). Control efficiency in this task is indexed by the *distractor effect*, the performance decline on incongruent compared with congruent trials. Based on research using this flanker task, Gratton et al. (1992) suggested that the focus of visual attention is adapted by individuals on the basis of recent performance. More specifically, Gratton and colleagues (1992, Experiment 1) discovered that the compatibility of the preceding trial influenced the behaviour on the current trial. The distracting effect of the flankers was weaker on trials following an incongruent trial than on trials that followed a congruent one. In particular, on a congruent trial, RT was shorter when the preceding trial was also congruent than when the preceding trial was incongruent. Likewise, on an incongruent trial, RT was slightly shorter when the previous trial was an incongruent trial than when it was a congruent trial. Figure 1A shows this RT pattern. The key observation is that the difference in RT between incongruent and congruent trials was smaller following incongruent trials than following congruent trials.

Gratton et al. (1992) distinguished between two types of attentional strategies for the flanker stimuli. First, with congruent stimuli in which no response conflict exists between target and flankers, participants may adopt a *wide* (also called *parallel* or *open*) processing strategy. All stimuli in the string are being processed simultaneously, without special focus on the target. Target identification is very fast, but also vulnerable to the influences of the distractors. Second, with incongruent

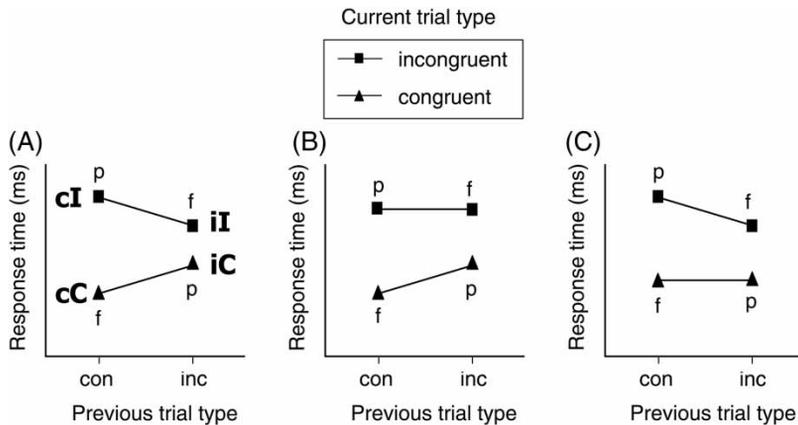


Figure 1. Illustration of different response time (RT) patterns underlying the Gratton effect reported in the literature. (A) RT effects on both current-congruent and current-incongruent trials. (B) RT effect on current-congruent trials only. (C) RT effect on current-incongruent trials only. “p” = partial repetition, “f” = full repetition or alternation. c, C, con = congruent; i, I, inc = incongruent.

stimuli, participants may adopt a *narrow* (sometimes also referred to as *focused* or *closed*) processing strategy. Special attention is given to the processing of the central target while the processing of the nearby distractors is suppressed. This narrow strategy ensures that identification of an incongruent stimulus is highly accurate, but the processing time is usually longer than that for the wide strategy.

To explain their RT pattern, Gratton et al. (1992) proposed that participants expect each upcoming trial to be of the same type as the previous trial and adjust their attentional strategy likewise (the congruency “repetition expectancy account”, cf. Egner, 2007). Thus, after a congruent trial, participants select the wide strategy to process the stimulus on the next trial, whereas after an incongruent trial, participants use the narrow strategy. However, on an incongruent trial that follows a congruent trial, henceforth referred to as a cI trial, the wide strategy is in fact not suitable for that incongruent stimulus. Processing the flankers, switching back to the narrow strategy, or double-checking the prepared response costs extra time. Consequently, the response time of a cI trial is delayed compared to an iI trial (an incongruent trial that follows an incongruent trial). Similarly, on an iC trial (a congruent trial that follows an incongruent trial), the

employed narrow strategy was not necessary for that congruent stimulus and increases the response time a little compared with that on a cC trial (a congruent trial that follows a congruent trial). Recently, further evidence for this repetition expectancy account was provided by an event-related brain potential (ERP) study. Bartholow et al. (2005) showed that in a flanker task the correct response negativity (CRN), an ERP component associated with response selection, was larger to incongruent trials when congruent trials were expected and was larger to congruent trials when incongruent trials were expected. These authors proposed that the CRN signals the inappropriateness of the attentional strategy (wide vs. narrow) that was selected on the basis of probability information about the upcoming stimulus type (congruent vs. incongruent) and the need to switch to the other strategy.

Gratton and colleagues (1992) observed that the error rate was about 10% lower in iI trials than in cI trials. However, the difference in response time between these conditions was found to be only 3 ms. Thus, the original Gratton RT pattern was almost exclusively determined by current-congruent trials (namely, faster responses on cC trials than on iC trials), as illustrated in Figure 1B. The illustrated pattern of RTs was also obtained by Ullsperger, Bylsma, and Botvinick (2005) and

Freitas, Bahar, Yang, and Banai (2007) using a flanker task. This raises the question of why the widening of attention does not (much) increase RTs on cI trials (incongruent following congruent; wide attention) compared with iI trials (incongruent following incongruent; narrow attention). A possibility is that responding is generally slowed following incongruent trials (slowing both iC and iI trials) or hastened following congruent trials (speeding up both cC and cI trials) and that such a general slowing or speeding up offsets the effect of widening of attention on cI trials. For example, following incongruent trials, participants may be more cautious and adopt a more stringent response criterion (e.g., Meyer, Roelofs, & Levelt, 2003) or engage in more extensive self-monitoring (e.g., Roelofs, 2004) after response selection. We take up this issue again in the General Discussion section of this article, where we present the results of computer simulations demonstrating the utility of this two-factor account.

Regardless of the cause of the absence of an RT effect on current incongruent trials, given that the first experiment of Gratton et al. (1992) did not include neutral trials, it is unclear whether the Gratton effect resulted from attentional widening following congruent trials, narrowing following incongruent trials, or both. Evidence in favour of attentional widening based on expected congruency came from another experiment reported by Gratton et al. (1992, Experiment 3a) using symbolic cues that predicted with 20%, 50%, or 80% certainty that the upcoming Eriksen flanker stimulus would be congruent (as opposed to be incongruent). The difference in RT between incongruent and congruent trials was larger with the 80% congruent-predicting cues than with the 80% incongruent-predicting cues and neutral 50%-each cues (i.e., 50% congruent or incongruent), whereas the latter two cue types did not differ from each other in the magnitude of the distractor effect. Taken together, the data of Gratton et al. suggest that strategic control adjustments mainly arise from expecting congruent trials.

However, a decade ago another explanation for the Gratton effect was put forward, which also considers the sequential effect to be an indication

for strategic adjustments in control settings, but supposes a different underlying nature of the processing strategy. Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) obtained RTs in a brain imaging study using an arrow version of the classic Eriksen flanker stimuli. Participants were presented with strings of five arrow-heads (e.g., <<<<< or <<><<) and had to indicate manually the direction of the central character as quickly and accurately as possible. Behavioural data reflected the sequential effect reported by Gratton et al. (1992) in the sense that the distractor effect (incongruent minus congruent) was larger for trials following congruent trials than for trials following incongruent trials (unfortunately, mean RTs for the cC, cI, iC, and iI trial types were not given). Responses on iI trials were said to be faster than those on cI trials for 8 of the 11 participants. Botvinick et al. (1999) argued that “the most interesting implications of the Gratton effect relate specifically to incompatible trials” (p. 179). Because in this study, adjustments in control seem to arise following experienced response conflict, Botvinick and colleagues stated that the Gratton effect reflects *conflict adaptation* following response conflict on incongruent trials, consisting of a narrowing of attention.

The idea that attentional control is triggered by response conflict was further elaborated and computationally modelled by Botvinick et al. (2001) and Yeung, Cohen, and Botvinick (2004). This *conflict-monitoring* model has become a dominant view in the literature on attentional control processes. It postulates that when mutually incompatible responses are simultaneously activated in the brain (e.g., when processing an incongruent stimulus), a conflict-monitoring mechanism (presumed to be located in the dorsal anterior cingulate cortex, ACC) signals the need for more attentional control (although conflict may arise at other levels of information processing, the model is centred around response conflict). A strategic control mechanism (presumed to be located in the dorso-lateral prefrontal cortex) aims to resolve this conflict by top-down biasing the processing of the task-specific dimension (i.e., the central

character in the flanker task, see also Egner & Hirsch, 2005) and suppressing the task-irrelevant dimension—namely, the distractors (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Such conflict-driven adjustments result in a smaller distractor effect following an incongruent stimulus than following a congruent one: the Gratton effect.

Kerns et al. (2004) extended the conflict-monitoring theory by demonstrating that conflict adaptation is achieved not only with flanker stimuli, consisting of spatially separated targets and distractors, but also with spatially integrated stimuli—namely, colour-word Stroop stimuli. In the original experiments of Stroop (1935; see MacLeod, 1991, for a review), participants had to name the ink colour of colour words or series of Xs. They were slower in naming incongruent stimuli (e.g., saying “red” to the word BLUE in red ink) than neutral stimuli (e.g., saying “red” to a string of Xs in red ink). Using congruent and incongruent colour-word Stroop stimuli, Kerns et al. observed the Gratton effect in manual RTs in a brain imaging experiment. The distractor effect was 126 ms when the previous trial was congruent and only 70 ms when the previous trial was incongruent. Effects were only found on current-incongruent trials (i.e., *iI* trials were 56 ms faster than *cI* trials), as illustrated in Figure 1C. This suggests that following an incongruent trial, the attentional focus is narrowed more to the colour dimension. For current-congruent trials, it did not matter whether the preceding trial was congruent or incongruent. This provides further support for the conflict-monitoring theory’s base assumption that control adjustments are only evoked in response to incongruent trials. The obtained RT pattern raises the question why the narrowing of attention does not increase RTs on congruent trials following incongruent trials (*iC*) compared with congruent trials following congruent ones (*cC*). Kerns et al. suggested that this is because congruent trials are simply not much affected by the width of attention.

Sequential effects on both current-congruent and current-incongruent trials were obtained by Egner and Hirsch (2005), matching the RT

pattern depicted in Figure 1A. This brain imaging study used a face–word variant of the colour-word Stroop task, in which names of actors and politicians were superimposed on photos showing faces of famous actors or politicians. The face–name combinations formed congruent and incongruent stimuli. Depending on the task, participants had to manually categorize either the name or the face as “actor” or “politician”. In line with all previous studies, Egner and Hirsch obtained a Gratton effect: The distractor effect was larger following a congruent trial than following an incongruent trial. However, in this study the sequential effect manifested itself on both congruent and incongruent trials (see also Bartholow et al., 2005; Burle, Allain, Vidal, & Hasbroucq, 2005; Kunde, 2003; Nieuwenhuis & Yeung, 2005; Notebaert, Gevers, Verbruggen, & Liefoghe, 2006). However, because neutral trials were lacking, it is unclear whether the RT pattern was the result of experienced response conflict, expected response facilitation, or both.

As outlined above, it is currently unclear what precise condition (incongruent, congruent, or both) triggers attentional control adjustments and thus whether the presence of response conflict is necessary. Recent studies complicate the picture further by suggesting that the Gratton effect does not emerge from strategic top-down adjustments in control settings, but instead results from retrieval advantages for specific stimulus–response pairs (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., 2006; Notebaert, Soetens, & Melis, 2001). Note that when only two distractor conditions (congruent and incongruent) are used with just two different stimuli for each condition, exact stimulus repetitions will occur in about 50% of the *cC* and *iI* trials and never in the *cI* and *iC* trials, which contain only partial stimulus repetitions. The occurrences of full stimulus repetitions are indicated by “f” in Figure 1 and partial repetitions by “p”. It is well known that stimulus-specific priming improves the processing of the stimulus and thus reduces the RT (e.g., Hamberger & Friedman, 1992; Kraut & Smothergill, 1978). Therefore, greater repetition priming effects for

full than partial stimulus repetitions could explain why responses on cC trials (full repetition) are faster than those on iC trials (partial repetition) and why responses on iI trials (full repetition) may be faster than those on cI trials (partial repetition), as Botvinick et al. (1999) found. Indeed, using the standard Eriksen flanker task, Mayr and colleagues (2003) found that the Gratton effect completely disappeared when all exact stimulus repetition trials were removed from the RT data analyses (for similar findings, see Nieuwenhuis et al., 2006). These authors therefore claimed that the Gratton effect does not stem at all from modulations in attentional control, but are simply the result of stimulus repetitions.

However, evidence against this repetition priming account was provided by Ullsperger et al. (2005), who found a Gratton effect with arrow head flanker stimuli even when they controlled for priming effects by including only target-alternation trials in the data analyses. Other studies also obtained the Gratton effect while controlling for repetition effects (e.g., Kerns et al., 2004; Notebaert et al., 2006; Wühr & Ansorge, 2005). Furthermore, Freitas et al. (2007) demonstrated that control adjustments are also made between successive trials when flanker and Stroop tasks are alternated. Apparently, attentional modulations are not evoked by the stimulus features but by the distractor condition. Given these findings, it seems likely that both attentional adjustment and feature priming effects contribute to the Gratton pattern separately (cf. Egner, 2007; Notebaert & Verguts, 2007).

In the past few years, research into the Gratton effect has expanded enormously. Although Nieuwenhuis and colleagues (2006) suggested that conflict adaptation might be restricted to Stroop (Kerns et al., 2004) and Simon tasks (Fischer, Plessow, & Kiesel, 2010; Ridderinkhof, 2002; Stürmer et al., 2002; Wühr & Ansorge, 2005), the Gratton effect has been observed with a large variety of tasks, including a prime–target interference task (Kunde, 2003), a spatial cueing task (Jongen & Smulders, 2007), the SNARC (spatial–numerical association of response codes) task (Notebaert & Verguts, 2008), and other

stimulus response compatibility tasks, where location was the relevant dimension (Stoffels, 1996). The Gratton effect is found to be item-nonspecific (Verguts & Notebaert, 2008), but may depend on the task that is used (Fernandez-Duque & Knight, 2008). In a review of the literature, Egner (2008) suggests that the effects of the adjustment in control settings are probably mediated by multiple, independent conflict-control loops that can operate in parallel. However, the underlying mechanism that triggers the adjustments in control remains unclear (cf. Fernandez-Duque & Knight, 2008). Egner (2007) argued that “the behavioral data show that neither conflict adaptation nor feature integration effects can account for all instances of the congruency sequence effect” (p. 388) and “even when controlling for feature integration effects, the interpretation of congruency sequence effects as reflecting conflict-driven control processes still hinges on the assumption that no other processes additionally impact this effect. This assumption may well be incorrect, and it is therefore crucial to identify possible additional contributors to this effect, such as expectancy-based control processes” (p. 389). Nevertheless, the central idea in most research is that the control adjustment underlying the Gratton effect is driven by response conflict (for a review, see Mansouri, Tanaka, & Buckley, 2009), thereby ignoring the original observation by Gratton et al. (1992) that adjustments can be independent of response conflict, at least for the Eriksen flanker task.

Plan of the present study

The central aim of the experiments reported in the present article was to investigate whether the presence or expectation of response conflict is necessary for adjustments in attentional control to be observed. To our knowledge, only two Gratton-type studies have used neutral stimuli (Kunde, 2003, with a prime–target interference task, and Wühr & Ansorge, 2005, with the Simon task). Consequently, from most studies it is unclear whether the Gratton effect indicates a speed-up of responding on cC (or iI) trials or prolonged

responding on cI (or iC) trials. We therefore included neutral trials in addition to congruent and incongruent ones in our experiments. We use the term *neutral* in a descriptive sense, indicating stimuli that do not evoke response conflict, like standard incongruent stimuli, or facilitate responding, like standard congruent stimuli. Given that recent research suggests that control adjustments may differ somewhat depending on the specific conflict task that is used (Magen & Cohen, 2007), we examined performance in both the Eriksen flanker task (Experiment 1) and the colour-word Stroop task (Experiment 2). Evidence from these two tasks has previously been taken as support for the conflict monitoring model (Botvinick et al., 2001; Yeung et al., 2004). The targets in our Eriksen flanker task were the letters S and H, and the neutral distractors were Os, which were not mapped onto any response. The targets in our colour-word Stroop task were the colours red and green, and the neutral distractors were Xs, which were not mapped onto any response. We are not assuming that our neutral stimuli are completely free of conflict. Presumably, our incongruent and neutral stimuli require some attentional focusing to identify the target, which may not be required by congruent stimuli. Nevertheless, our neutral distractors do not activate any response and therefore may serve to assess effects of response conflict from incongruent stimuli or facilitation from congruent stimuli.

All Gratton-type studies used manual responding, except for three recent studies using vocal responding (Fernandez-Duque & Knight, 2008; Freitas et al., 2007; Magen & Cohen, 2007). However, these studies did not include neutral trials. As a consequence, it is at present unclear whether the Gratton effect can be independent of response conflict in vocal responding. Producing speech requires a complex form of action planning involving multiple processing levels (e.g., Levelt, Roelofs, & Meyer, 1999; Roelofs, 2003), and it is therefore well conceivable that response modality interacts with the attentional control systems investigated in the current study (cf. Magen & Cohen, 2007; for a similar

account of response modality effects in Stroop task performance, see Roelofs, 2003). As a second objective, we therefore assessed the effect of response modality in the present study by having the participants respond manually and vocally in both tasks. Third, to address the issue of generalization of our findings, we not only examined trial-to-trial adjustments (Experiments 1 and 2), but also examined the effect of cue-based adjustments (Experiment 3), following Gratton et al. (1992). Participants were presented with neutral cues or congruent- or incongruent-predicting cues, and the Gratton effect following these cues was assessed. It is presently unclear whether such expectancy-based effects reflect the same type of strategic processing as the more thoroughly studied stimulus-driven effects (Egner, 2007). Wühr and Kunde (2008) stated that “it seems that preparation for stimulus or response conflict is a difficult task, and every demonstration of how to overcome this difficulty is welcome both for theoretical as well as for practical reasons” (p. 883).

Our predictions for all three experiments were as follows: If the Gratton effect concerns adaptation based on response conflict (Botvinick et al., 2001), the distractor effect should be smaller for postincongruent trials than for postcongruent and postneutral trials, whereas the distractor effect for postneutral trials should resemble that for postcongruent trials (after all, like congruent stimuli, a neutral stimulus is not associated with response conflict). In contrast, if the Gratton effect concerns an anticipation of upcoming response facilitation by widening attention, the distractor effect should be larger for postcongruent trials than for postincongruent and postneutral trials, whereas the distractor effect for postneutral trials and postincongruent trials should be the same (after all, a neutral stimulus does not predict an upcoming congruent stimulus). Finally, if the Gratton effect concerns a combination of widening of attention in anticipation of a congruent trial and narrowing of attention following incongruent trials, one might expect that the size of the distractor effect for postneutral trials lies somewhere in between the larger

postcongruent and the smaller postincongruent distractor effects.

EXPERIMENT 1

The purpose of the first experiment was to assess the nature of the Gratton effect in the Eriksen flanker task by including neutral trials in addition to incongruent and congruent ones. The participants responded both manually and vocally to assess the effect of response modality.

Method

Participants

Sixteen students from Nijmegen University (13 of them female) volunteered to participate in the experiment. Their age varied from 18 to 25 years with a mean of 21 years. All had normal or corrected-to-normal vision. Participants took part individually and were paid for their participation.

Apparatus

The experiment was conducted on two separate, connected microcomputers. The first computer generated the visual displays, and the second computer collected the experimental data. RTs were measured with an accuracy of 1 ms (1,000 Hz) by a voice key for the vocal responses and a button-box with two buttons for the manual responses. The participants were seated in front of a colour CRT monitor connected to the first computer, at a viewing distance of approximately 70 cm. On a second monitor connected to the data collection computer, the experimenter was shown the correct response and the participant's response latencies.

Materials and design

The displayed stimuli mirrored those from Gratton et al.'s (1992) first experiment and consisted of 6 five-letter arrays. These white capital characters (18-points Arial) were 6 mm high and 4.5 mm wide, corresponding to 0.5° by 0.4° of visual angle at a viewing distance of approximately 70 cm. The width of the entire string measured

25 mm (2° of visual angle). The background of the computer screen was black.

The character in the centre of the five-letter array formed the target and was always either an H or an S. The four other characters (two on each side of the target) formed flanker letters. Three distractor conditions were used. In the congruent condition, the four flankers were equal to the target (SSSSS and HHHHH), whereas in the incongruent condition, the flankers were associated with the alternative response (HSHSH and SSHSS). In the neutral condition, the flankers were different from the target, but they were not associated with any possible response (OOHOO and OOSOO).

The experiment consisted of 360 experimental trials, with a short break after every 90th trial. The presentation of the stimuli was pseudorandomized within a block of 90 trials, under such constraints that each of the nine possible trial sequences (e.g., incongruent–congruent or neutral–incongruent) occurred equally often.

All participants responded manually in one half of the experiment and vocally in the other half. The order of the response modality was counterbalanced across participants.

Procedure

The participants took part individually in a dimly illuminated, quiet room. The instruction for the first response modality (manual or vocal) was given on paper and was repeated orally by the experimenter. After 12 practice trials, 180 experimental trials followed, with a short break after the 90th trial. Then, the instruction for the second response modality was given both written and orally. Again, 12 practice trials were followed by 180 experimental trials, with a short break halfway. When the letter array appeared, the central character had to be identified. Participants were encouraged to react as quickly and accurately as possible. Incorrect responses in the vocal condition were classified online by the experimenter.

A trial went as follows: A visual cue (a small white asterisk) appeared at the centre of the screen. After 1 s, this location cue disappeared, and a five-letter array was presented, with the

position of the central character just above the previous cue. In the manual condition, the participants identified the central target (H or S) by pressing one of two buttons with the left and right index fingers (counterbalanced across participants). To make sure that response selection was as comparable as possible between the two response modalities, in the vocal condition participants had to identify the target character by saying aloud either “left” or “right” (counterbalanced across participants). After 1,500 ms the screen blanked for 1 s, and then the next trial started. The beginning of a break was indicated by the Dutch word *PAUZE* (*pause*) for 1,500 ms. The beginning of a block was preceded by the word *ATTENTIE* (*attention*) for 1,500 ms. An experimental session took about 30 min.

Results and discussion

The following data-trimming procedure was used: Trials for which RTs were longer than 1,500 ms or shorter than 200 ms, trials in which the voice key malfunctioned or triggered inappropriately (in combination, 0.66% of the data), and the trials in which the participant made an incorrect response (1.18% of the data) were discarded. To reduce post-error slowing effects (Rabbitt, 1966) each trial immediately following an incorrect response was omitted from analyses. Also, as the first trial of each block by definition has no preceding trial, these four trials were omitted from the RT analyses. The remaining RTs (95.87%) were used in calculations of means. The upper panel in Figure 2A shows the mean RTs as a function of trial sequence for manual, vocal, and overall responses. The lower panel in Figure 2A shows the obtained error percentages (only incorrect response trials, not voice key errors and timeouts, based on all trials except the four block-starting trials) for the same conditions.

Three-way repeated measures analyses of variance (ANOVAs) were conducted on the mean correct RTs, with current trial (congruent, incongruent, neutral), previous trial (congruent, incongruent, neutral), and response modality (vocal, manual) as within-participants factors. An

alpha level of .05 was used for all statistical tests. The RT analysis showed main effects of current trial, $F(2, 30) = 60.02$, $MSE = 1,130$, $p < .001$, an average distractor effect of 47 ms; previous trial, $F(2, 30) = 7.22$, $MSE = 563$, $p = .003$, mean response latencies were overall longest for postincongruent trials; and response modality, $F(1, 15) = 15.37$, $MSE = 28,331$, $p = .001$, indicating that manual responses were on average 78 ms faster than vocal responses. Current trial and previous trial interacted, indicating a sequential effect, $F(4, 60) = 7.58$, $MSE = 935$, $p = .001$. Response modality interacted neither with current trial ($p = .282$) nor with previous trial ($F < 1$). Moreover, the interaction between response modality, current trial, and previous trial was not significant, indicating that response modality had no influence on the Gratton effect, $F(4, 60) < 1$. Therefore, in the remaining analyses we collapsed the data over the factor response modality.

Pairwise comparisons revealed that the distractor effect (incongruent minus congruent) was larger for postcongruent trials than for postincongruent trials, the classic Gratton effect. Post hoc comparisons showed that the distractor effect was smaller for postneutral trials than for postcongruent trials and that the distractor effect was similar for postneutral and postincongruent trials. Figure 2B shows the magnitudes of the distractor effects and the corresponding p -values.

Further analyses were conducted to investigate the underlying RT pattern. In the literature on the Gratton effect, the distractor effect is always smaller following an incongruent trial than following a congruent trial. However, this Gratton effect resulted from an RT difference on current-congruent trials (Gratton et al., 1992), an RT difference on current-incongruent trials (Kerns et al., 2004), or a combination of both (Egner & Hirsch, 2005). In our experiment, paired comparisons showed that for current-congruent trials, responses were significantly slower following an incongruent trial than following a congruent trial, $F(1, 15) = 19.47$, $MSE = 477$, $p = .001$, whereas for current-incongruent trials, the nature of the preceding trial had no influence on the RT, $F(1, 15) = 0.613$, $MSE = 226$, $p = .446$.

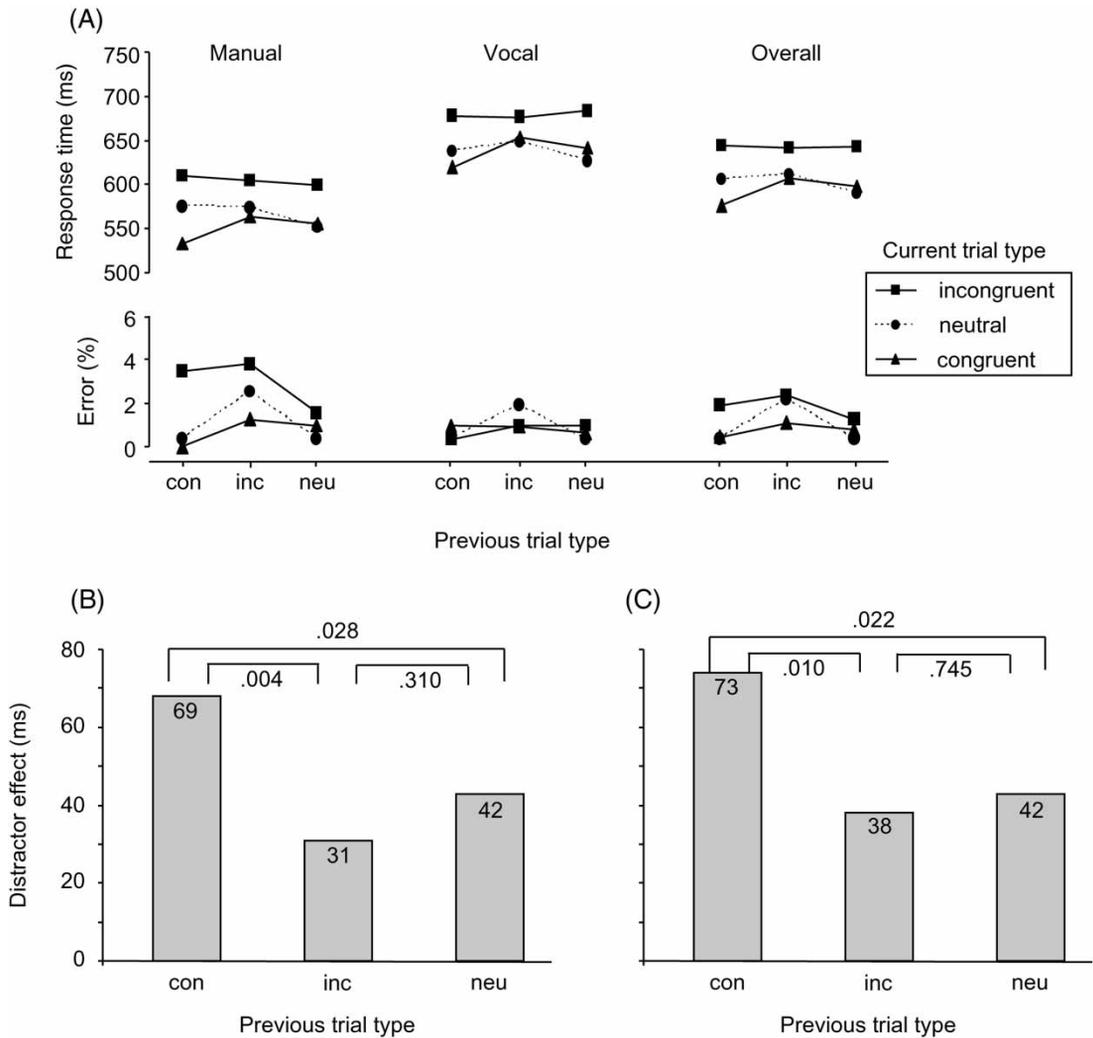


Figure 2. Results of Experiment 1 with Eriksen flanker stimuli. (A) Mean response times and incorrect response percentages as a function of current trial type and previous trial type for manual, vocal, and overall data. (B) Overall distractor effects (incongruent minus congruent) and the corresponding p-values following congruent, incongruent, and neutral trials. (C) Overall distractor effects (incongruent minus congruent) and the corresponding p-values when full stimulus repetitions are omitted from analyses to control for priming effects. con = congruent, inc = incongruent, neu = neutral.

As can be seen in Figure 2A, the error pattern resembled the RT pattern. Error rates were slightly lower in the faster conditions, suggesting that no speed-accuracy trade-off occurred in the data. As the number of errors was very low (1.18%), these were not further analysed.

In short, the results of Experiment 1 replicate and extend the finding of Gratton et al. (1992)

obtained with Eriksen flanker stimuli. The distractor effect is smaller following an incongruent stimulus than following a congruent stimulus (i.e., the Gratton effect). Furthermore, the distractor effect is larger following congruent trials than following neutral trials, whereas the distractor effect does not differ following incongruent and neutral trials. As could be expected, RTs in

the vocal condition were slower than those in the manual condition (on average 78 ms). However, the Gratton patterns were very similar. Therefore, we can safely conclude that the response modality (vocal versus manual) had no influence on the observed Gratton effect.

As mentioned in the introduction, an alternative account for the Gratton effect was proposed recently. According to this repetition account, the observed RT pattern would not indicate attentional adjustments, but simply result from priming effects due to exact stimulus repetitions (Mayr et al., 2003; Nieuwenhuis et al., 2006). To ensure that the Gratton pattern in our experiment actually arose from modifications in attentional control, we reanalysed our data, this time excluding all trials for which the preceding trial had an identical stimulus. Note that this occurs only in the cC, iI, and nN trials. After having removed the stimulus repetitions, the results were virtually identical to those obtained when the stimulus repetitions were still included (see Figure 2C). Most important, the interaction between current trial (con, inc, neu) and previous trial (con, inc, neu) was still significant, $F(4, 60) = 7.69$, $MSE = 554$, $p < .001$. Pairwise comparisons revealed that the distractor effect was larger for postcongruent trials than for postincongruent and postneutral trials, whereas the latter two did not differ. See Figure 2C for the corresponding p -values. To conclude, the Gratton effect observed in the present experiment is not caused by exact stimulus repetition priming.

The RT difference between incongruent and congruent trials was larger for postcongruent trials than for postincongruent and postneutral trials. This pattern of results suggests that the adjustments were independent of response conflict, contrary to what the conflict-adaptation hypothesis holds. However, the RT patterns also do not agree with the expectation hypothesis. Expectation is a two-sided mechanism, with behavioural benefits when expected events occur

and costs when unexpected events occur. The hypothesis explains why congruent–congruent trials (expected) were faster than incongruent–congruent trials (unexpected). However, the expectation hypothesis would also predict that congruent–incongruent trials (unexpected) should be slower than incongruent–incongruent trials (expected), but this is not what we observed. In the experiment, the RTs on incongruent trials were independent of the previous trial type. Thus, our data challenge both the conflict-monitoring and expectation hypotheses.

EXPERIMENT 2

After investigating the Gratton effect using flanker stimuli, the purpose of the second experiment was to assess the nature of the Gratton effect in the colour-word Stroop task while including neutral trials in addition to incongruent and congruent ones. Although response modality had no influence on the overall Gratton pattern with Eriksen flanker stimuli in the previous experiment, participants responded again both manually and vocally to assess a possible effect of response modality with Stroop stimuli.

Method

Participants

Thirty-two students from Nijmegen University (27 of them female) volunteered to participate in the experiment.¹ Their age varied from 18 to 33 years with a mean of 22 years. All had normal or corrected-to-normal vision. The participants took part individually and were paid for their participation.

Apparatus

The apparatus configuration used in this experiment was identical to that in Experiment 1.

¹After testing the planned 16 participants, we observed smaller distractor effects than we expected. To increase the statistical power, we doubled the number of participants compared to the previous experiment with flanker stimuli.

Materials and design

The displayed stimuli consisted of coloured rectangular bars and written distractor colour words. The stimuli were 49 mm × 17 mm (corresponding to 4° × 1.4° of visual angle at a viewing distance of approximately 70 cm). To minimize the differences between this experiment and Experiment 1 (in order to be able to generalize the results), we used only two different colours and colour words. The stimuli consisted of red and green target bars and the following Dutch colour words: ROOD (*red*) and GROEN (*green*). The distractor words were superimposed in white upper-case letters on the colour bar, forming semi-integral Stroop stimuli (cf. Lamers & Roelofs, 2007). The background of the computer screen was black.

Three distractor conditions were used: congruent, neutral, and incongruent. The congruent stimuli consisted of the two matching colour bar–colour name pairs (red bar–ROOD, green bar–GROEN). The incongruent stimuli were nonmatching colour pairs (red bar–GROEN, green bar–ROOD). The neutral stimuli resulted from the two colour bars with an XXXXX-string superimposed on it.

The experiment consisted of 360 experimental trials, with a short break after every 90th trial. As in Experiment 1, the presentation of the stimuli was pseudorandomized within a block of 90 trials, with the boundary condition that the first-order sequential effects were equilibrated; that is, each distractor condition was followed by each other distractor condition the same number of times, and the maximum number of stimulus repetitions was set to three.

All participants responded manually in one half of the experiment and vocally in the other half. The order of the response modality was counterbalanced across the participants.

Procedure

The procedure for this experiment resembled that in Experiment 1, except that the task of the participant was now to identify the colour of the rectangular bar, as soon as the colour-word Stroop stimulus appeared. The participants were

encouraged to react as quickly and accurately as possible, while trying to ignore the distractor word.

A trial went as follows: A colour-word Stroop stimulus appeared at the centre of the screen and remained visible for 1,500 ms. In the manual condition, the participants identified the colour by pressing one of two buttons with the left and right index fingers (counterbalanced across participants). In the vocal condition, the participants identified the target colour by saying aloud “red” or “green”. After 1,500 ms the screen blanked for 1 s, and then the next trial started. The beginning of a break was indicated by the Dutch word PAUZE (*pause*) for 1,500 ms. The start of a block was preceded by the word ATTENTIE (*attention*) for 1,500 ms. An experimental session took about 30 min.

Results and discussion

The same data trimming procedure as that for Experiment 1 was used. The following trials were discarded from RT analyses: trials for which the RTs were shorter than 200 ms, longer than 1,500 ms, or in which the voice key malfunctioned or triggered inappropriately (in combination, 1.12% of the data); trials in which the participant hesitated or made an incorrect response (1.13% of the data); the four block-starting trials; and the posterror trials. Mean RTs were calculated over the remaining trials (95.7%). The upper panel in Figure 3A shows the mean RTs as a function of trial sequence for manual, vocal, and overall responses for Experiment 2. The lower panel in Figure 3A shows the obtained error percentages for the same conditions.

A repeated measures ANOVA was performed on the mean correct RTs, with current trial (congruent, incongruent, neutral), previous trial (congruent, incongruent, neutral), and response modality (vocal, manual) as within-participants factors. An alpha level of .05 was used for all statistical tests. The RT analysis showed main effects of current trial, $F(2, 62) = 26.26$, $MSE = 1,701$, $p < .001$, an average distractor effect of 23 ms; of previous trial, $F(2, 62) = 8.77$, $MSE = 362$,

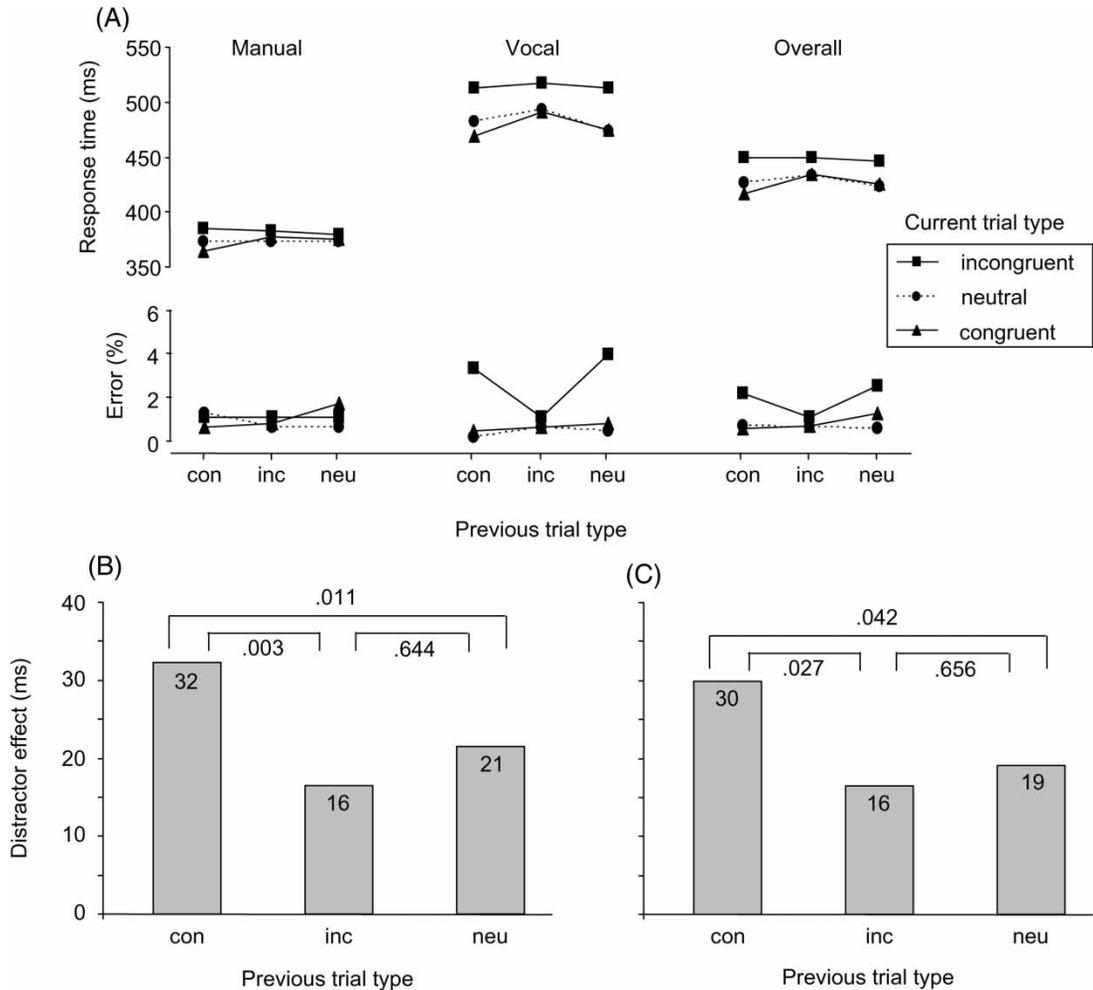


Figure 3. Results of Experiment 2 with colour–word Stroop stimuli. (A) Mean response times and incorrect response percentages as a function of current trial type and previous trial type for manual, vocal, and overall data. (B) Overall distractor effects (incongruent minus congruent) and the corresponding p-values following congruent, incongruent, and neutral trials. (C) Overall distractor effects (incongruent minus congruent) and the corresponding p-values when full stimulus repetitions are omitted from analyses to control for priming effects. con = congruent, inc = incongruent, neu = neutral.

$p = .001$, mean response latencies were longest following an incongruent trial; and of response modality, $F(1, 31) = 184.50$, $MSE = 10,604$, $p < .001$, manual responses were on average 116 ms faster than vocal responses. The interaction of most importance to our purposes, current trial by previous trial, was significant, $F(4, 124) = 3.21$, $MSE = 513$, $p = .025$, an indication of a sequential effect. The three-way interaction between response modality, current trial, and

previous trial was not significant, $F(4, 124) = 1.12$, $MSE = 445$, $p = .351$, indicating that response modality had no influence on the Gratton effect, exactly as in Experiment 1. Therefore, in the remaining analyses we collapsed the data over the factor response modality.

Post hoc comparisons showed that the Gratton effect was obtained: The distractor effect was larger for postcongruent trials than for postincongruent trials. Furthermore, the distractor effect for

postneutral trials was smaller than for postcongruent trials, but similar to that for postincongruent trials. Figure 3B shows the magnitudes of the distractor effects and the corresponding p -values. Further post hoc analyses showed that for current-congruent trials, responses were significantly slower for postincongruent trials than for postcongruent trials ($p < .001$), whereas for current-incongruent trials the nature of the preceding trial had no influence on the latencies ($F < 1$).

As can be seen in Figure 3A, the error pattern resembled the RT pattern, except that the error rate for iI trials was extremely low for vocal responses. Overall, error rates were slightly lower in the faster conditions, suggesting that no speed-accuracy trade-off occurred in the data. As the number of errors was very low (1.1%), these were not further analysed.

To conclude, the results of Experiment 2 for colour-word Stroop stimuli confirm and extend the findings obtained with Eriksen flanker stimuli in the Gratton et al. (1992) study and the present Experiment 1. The Gratton effect is observed: The distractor effect is smaller after an incongruent stimulus than after a congruent stimulus. Furthermore, since the distractor effect is the same following incongruent and neutral trials, the data indicate that the sequential effect is not obtained because the participants make adaptations after response conflict, which is absent on neutral trials. The results also show that only for current-congruent trials are response latencies influenced by the compatibility of the preceding stimulus. As in Experiment 1, the response modality (vocal versus manual) had no influence on the observed Gratton effect, this time obtained with Stroop stimuli.

To investigate whether stimulus priming played a role in this experiment, as Mayr et al. (2003) suggested for the Eriksen flanker task, we reran the previous analyses on our data set, after removing all trials in which the stimulus was preceded by an identical stimulus (both colour and word). As shown in Figure 3C, when controlled for stimulus repetition effects, the interference effect for postcongruent trials was still larger than that for

postincongruent and postneutral trials, whereas the latter two did not differ. Thus, the Gratton effect observed in the present experiment is not caused by repetition priming.

As in Experiment 1, the RT difference between incongruent and congruent trials was larger for postcongruent trials than for postincongruent and postneutral trials. This pattern of results suggests that the adjustments were independent of response conflict, contrary to what the conflict-adaptation hypothesis holds. However, the RT patterns also do not agree with the expectation hypothesis. The hypothesis predicts that congruent-congruent trials (expected) should be faster than incongruent-congruent trials (unexpected), as obtained. However, the hypothesis also predicts that congruent-incongruent trials (unexpected) should be slower than incongruent-incongruent trials (expected), but this is not observed. As in Experiment 1, the RTs on incongruent trials were independent of the previous trial type. Thus, our data challenge both the conflict-monitoring and the expectation hypotheses.

EXPERIMENT 3

Our first two experiments indicated that the amount of interference in RTs is equal following an incongruent and a neutral trial, whereas the distractors have a larger influence following a congruent trial. This suggests that these control adjustments were not triggered by response conflict. However, our data also did not support the predictions of the expectation account. Still, many instances of cognitive control are prospective in nature, arising from expectancies based on explicit cues about the compatibility of the upcoming stimulus (Egner, 2008). Trial-to-trial (Experiments 1 and 2) and cue-based adjustments have sometimes been treated as equivalent instances of strategic processing, but they seem in fact to be based on somewhat different mechanisms (Egner, 2007). Indeed, recent research (Alpay, Goerke, & Stürmer, 2009; Fernandez-Duque & Knight, 2008) presented evidence showing that the underlying processes may be quite different for these two instances of attentional

control adjustment. Therefore, it is important to assess whether our finding from Experiments 1 and 2 (i.e., adjustments of attentional control can be independent of response conflict) can be extended to cue-based modulations (cf. Aarts & Roelofs, in press; Aarts, Roelofs, & Van Turennout, 2008). Experiment 3 was designed to investigate this issue empirically in the colour-word Stroop task, by using informative cues that were predictive of the upcoming compatibility (congruent vs. incongruent) or that were neutral regarding the upcoming stimulus. Also, as the modulations should be based on the cue instead of the preceding stimulus, repetition priming effect should be minimized, which was further enforced by increasing the stimulus set in the experiment. As the response modality had no effect in the first two experiments, we measured now only vocal responses to increase the statistical power.

Method

Participants

Sixteen students from Nijmegen University (14 of them female) volunteered to participate in the experiment. Their age varied from 18 to 25 years with a mean of 20 years. All had normal or corrected-to-normal vision. The participants took part individually and were paid for their participation.

Apparatus

The apparatus configuration used in this experiment was identical to that in Experiments 1 and 2.

Materials and design

Three white cues were used: a plus-sign, a minus-sign, and a zero, all fitting within an invisible box sized 6.1 mm × 6.1 mm (corresponding to 0.5° × 0.5° of visual angle at a viewing distance of approximately 70 cm). Furthermore, as in Experiment 2, the displayed stimuli consisted of coloured rectangular bars and written distractor colour words. The stimuli were 49 mm × 17 mm (corresponding to 4° × 1.4° of visual angle at a viewing distance of approximately 70 cm). Red, green, and blue target bars were

used and the following Dutch colour words: ROOD (*red*), GROEN (*green*), and BLAUW (*blue*). The distractor words were superimposed in white upper-case letters on the colour bar. The background of the computer screen was black.

Two distractor conditions were used: congruent and incongruent. The congruent stimuli consisted of the three matching colour bar–colour name pairs (red bar–ROOD, green bar–GROEN, blue bar–BLAUW). The incongruent stimuli were nonmatching colour pairs (red bar–BLAUW, green bar–ROOD, blue bar–GROEN).

Three cue conditions were used: A plus-sign indicated an 80% chance that the upcoming stimulus would be congruent (and thus only 20% chance on an incongruent stimulus). A minus-sign indicated the opposite: 80% chance on an incongruent stimulus. A zero-sign was noninformative: 50% chance on either a congruent or an incongruent stimulus.

The experiment consisted of 360 experimental trials (180 congruent and 180 incongruent). The three cues were presented 120 times each, in such a manner that a plus-sign, a zero-sign, and a minus-sign were followed by a congruent stimulus in, respectively, 80%, 50%, and 20% of the trials. Within these constraints, the presentation of the stimuli was randomized within a block of 90 trials. All participants responded vocally.

Procedure

The participants took part individually in a dimly illuminated, quiet room. The instruction was given on paper and was repeated orally by the experimenter. After a representative subset of 30 practice trials, 360 experimental trials followed, with a short break after every 90th trial. The task of the participants was to identify the colour of the rectangular bar, as soon as the colour-word Stroop stimulus appeared. They were informed that a zero-cue is noninformative, whereas a plus-cue indicates a high chance on an upcoming congruent stimulus, and a minus-sign indicates a high chance on an upcoming incongruent stimulus. The participants were encouraged to actively use this cue information in the stimulus processing and to react as quickly and accurately as possible.

A trial went as follows: A small white cue (+, −, or 0) appeared in the centre of the screen. After 250 ms, this cue disappeared, and the screen stayed blank for 1,250 ms. Then, a colour-word Stroop stimulus appeared at the centre of the screen and remained visible for 1,500 ms. The participants identified the target colour by saying aloud “rood”, “groen”, or “blauw”. Finally, the screen blanked for 1 s, and then the next trial started. The beginning of a break was indicated by the Dutch word PAUZE (*pause*) for 1,500 ms, whereas the start of a block was preceded by the word ATTENTIE (*attention*) for 1,500 ms. An experimental session took about 40 min.

Results and discussion

The same data-trimming procedure as before was used: RTs longer than 1,500 ms, RTs shorter than 200 ms, RTs for trials in which the voice key malfunctioned or triggered inappropriately (in combination, 2.2% of the data), RTs for trials in which the participant made an incorrect response (2.5% of the data), the four block-starting trials, and the posterror trials were discarded from RT analyses. Mean RTs were calculated over the remaining trials (92.1%). The upper panel in Figure 4A shows the mean RTs as a function of cue and distractor type for previous-congruent, previous-incongruent, and overall responses for Experiment 3. The lower panel in Figure 4A shows the obtained error percentages for the same conditions.

Three-way repeated measures ANOVAs were conducted on the mean correct RTs, with cue (80% congruent-predicting, 50%-each, and 80% incongruent-predicting), current trial (congruent, incongruent), and previous trial (congruent, incongruent) as within-participants factors. An alpha level of .05 was used for all statistical tests. The RT analysis showed a main effect of current trial, $F(1, 15) = 49.68$, $MSE = 9,287$, $p < .001$, an average distractor effect of 98 ms. There were no significant main effects of cue and previous trial, nor was there an interaction between them ($F_s < 1$). Importantly, cue and current trial interacted, $F(2, 30) = 15.99$, $MSE = 1,525$, $p < .001$,

an indication that the Gratton effect was obtained based on cues. Interestingly, current trial also interacted with previous trial, $F(1, 15) = 6.97$, $MSE = 852$, $p = .019$, the distractor effect was 22 ms smaller following an incongruent trial than following a congruent trial. This indicates that besides the cue, the Gratton effect emerged from a second source as well. However, when all exact stimulus repetitions were removed from analyses, this interaction was no longer significant ($F < 1$), suggesting that the trial-to-trial effect was a repetition priming effect and not a true attentional adjustment. The interaction between cue, current trial, and previous trial was far from significant ($F < 1$), indicating that the effects that cue and previous trial have on the current trial are not related. As our main interest here concerns effects of the cue, we collapsed the data over the factor previous trial in the remaining analyses.

Post hoc comparisons revealed that the distractor effect was larger for 80% congruent-predicting cues than for the 80% incongruent-predicting cues, whereas the distractor effect for 50%-each cues was in between the two other cue types. This corresponds to the RT patterns that Aarts and Roelofs (in press) observed using probabilistic cues in a manual arrow-word version of the Stroop task. Figure 4B shows the magnitudes of the distractor effects and the corresponding p -values. Figure 4C shows these overall distractor effects and the p -values when exact stimulus repetitions are omitted from analyses to control for repetition priming effects. Inspection of Figures 4B and 4C confirms that the stimulus repetition effect has virtually no influence on the attentional adjustment based on the cue.

As can be seen in Figure 4A, the error pattern resembled the RT pattern, except that an 80% congruent-predicting cue that was followed by an incongruent stimulus led to a huge number of errors. More errors were made in the (slow) current-incongruent than in the current-congruent condition. Overall, error rates were lower in the faster conditions, suggesting that no speed-accuracy trade-off occurred in the data. Error rates were not further analysed.

The results of Experiment 3 show that the magnitude of the distractor effect depended on

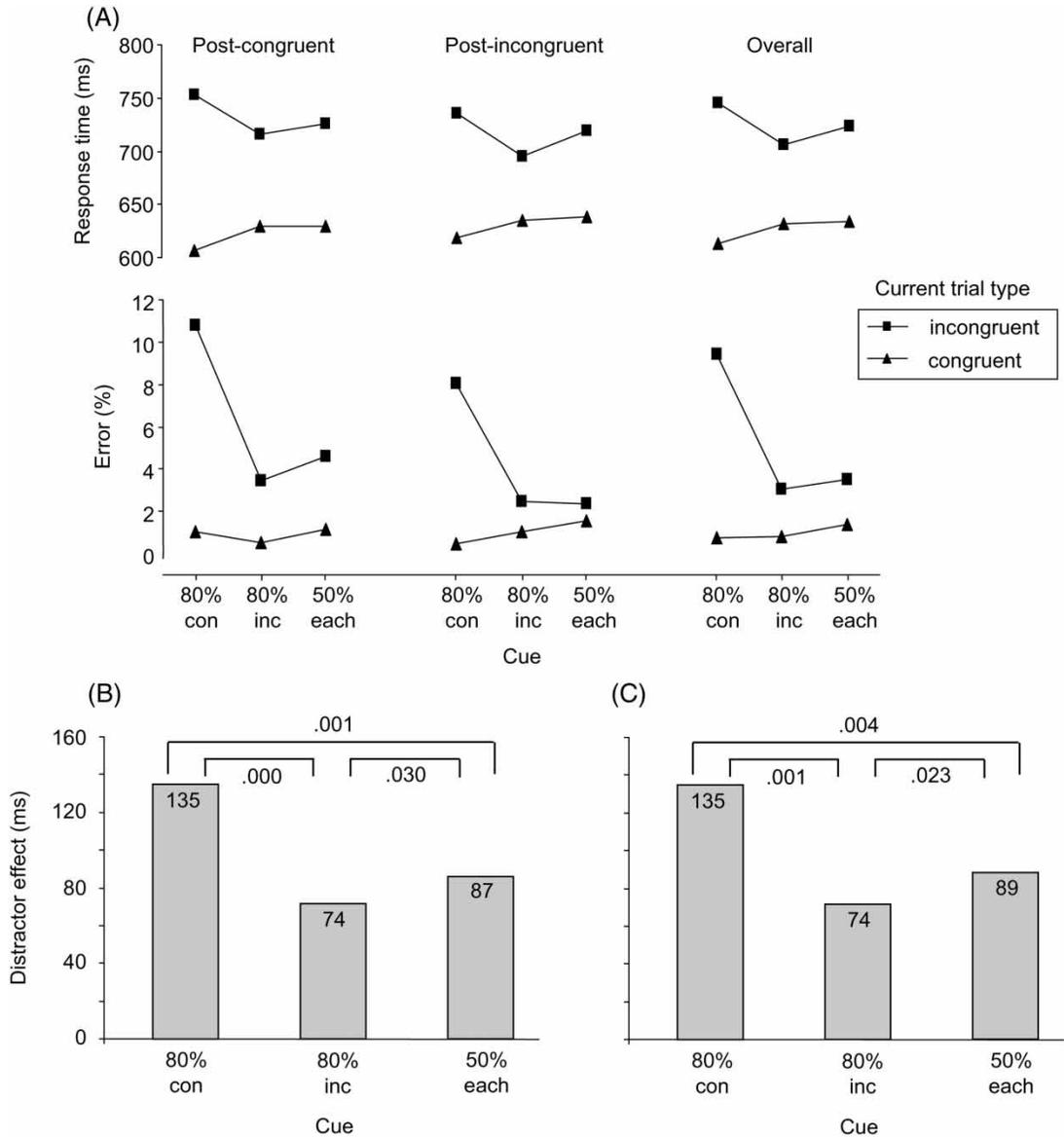


Figure 4. Results of Experiment 3 with predictive cues and colour-word Stroop stimuli. (A) Mean response times and incorrect response percentages as a function of current trial type and cue type (80% congruent-predicting, 80% incongruent-predicting, 50% each) for postcongruent, postincongruent, and overall data. (B) Overall distractor effects (incongruent minus congruent) and the corresponding p-values for each cue condition. (C) Overall distractor effects (incongruent minus congruent) and the corresponding p-values for each cue condition when full stimulus repetitions are omitted from analyses to control for priming effects.

the expected compatibility of the upcoming stimulus. In particular, the distractor effect was 58 ms larger when a congruent stimulus was anticipated than when an incongruent stimulus was expected

(i.e., the Gratton effect). The data provide evidence that the top-down modulations in attentional control do not necessarily have to be based on experienced response conflict. As a separate

issue, it is interesting to see that the compatibility of the preceding trial also had an independent influence on the distractor effect, although this effect completely disappeared when all exact stimulus repetitions were omitted from data analyses. This indicates that repetition priming can contribute partly to the Gratton effect (Mayr et al., 2003; Nieuwenhuis et al., 2006), but it is not sufficient to explain the results in Experiment 3 (compare Figures 4B and 4C; see Notebaert & Verguts, 2007, for a similar conclusion based on a multiple regression approach). Instead, the data of Experiment 3 indicate a role for top-down adjustments of control settings that cannot be accounted for by repetition priming effects.

We turn now to the effect of neutral cues. The analyses indicated that a neutral 50%-each cue was associated with a smaller distractor effect than an 80% congruent-predicting cue. The difference in distractor effect for 50%-each cues and 80% incongruent-predicting cues was relatively small (13 ms), although significant (see Figure 4B). Neutral cues are different from the neutral stimuli in Experiments 1 and 2 in the sense that after a neutral stimulus, participants may expect another neutral stimulus (neither help nor competition from distractors), whereas after a neutral cue, participants do not know whether to expect a congruent or an incongruent stimulus (but never a neutral stimulus in this experiment). It may be that they adopted a narrower attentional setting after 80% incongruent-predicting cues than after 50%-each cues. Regardless of the cause of this difference between experiments, the crucial observation is that Experiment 3 shows that attention is modulated by expectancies independent of repetition priming effects and that distractor effects are much larger in anticipation of a congruent stimulus than of an incongruent stimulus. Our finding is in line with a recent study by Wühr and Kunde (2008), who observed a modulating effect of congruent-predicting cues, but not of incongruent-predicting cues in a three-choice Simon task. Also, in studying effects of probabilistic cueing in a functional magnetic resonance imaging (fMRI) study, Aarts and Roelofs

(in press) observed differential ACC activity to targets following 75% congruent-predicting cues, but not following 75% incongruent-predicting and neutral (50%–50%) cues. Thus, if expectations are explicitly manipulated by symbolic cues, again response conflict seems not to be the trigger for the control adjustments.

GENERAL DISCUSSION

Using the flanker task (Eriksen & Eriksen, 1974), Gratton and colleagues (1992) obtained data suggesting that participants adjust their attention settings on a trial-by-trial basis, based on expectations that arise from the compatibility of the preceding trial. The effect of the flankers is smaller following an incongruent trial than following a congruent trial. In the present study, we replicated this Gratton effect with flanker stimuli (Experiment 1), and we confirmed that the effect also occurs with colour-word Stroop stimuli (Experiment 2). Moreover, in both tasks, the RT difference between incongruent and congruent trials (i.e., the distractor effect) was larger for postcongruent trials than for postincongruent and postneutral trials, whereas the latter two yielded the same RT difference. These results were obtained regardless of response modality and were shown to be independent of exact stimulus repetition. This pattern of results suggests that the adjustments were independent of response conflict, contrary to what the conflict-adaptation hypothesis holds (Botvinick et al., 2001). However, the results also do not agree with the expectation hypothesis (Gratton et al., 1992). According to the expectation hypothesis, RTs should be shorter on congruent–congruent (expected) than on incongruent–congruent (unexpected) trials, as observed. However, RTs should be longer on congruent–incongruent (unexpected) than on incongruent–incongruent (expected) trials, which was not supported by our data. Thus, the results of Experiments 1 and 2 challenge both the conflict-monitoring and the expectation hypotheses.

In Experiment 3, we explicitly manipulated the expectancies about the upcoming stimulus condition (incongruent, congruent) by symbolic cues. Again, the distractor effect was largest when a congruent trial was expected, independent of upcoming response conflict. However, now RTs were shorter on congruent–congruent (expected) than incongruent–congruent (unexpected) trials, and RTs were longer on congruent–incongruent (unexpected) than on incongruent–incongruent (expected) trials, exactly as predicted by the expectation hypothesis. This suggests that expectations may drive attentional control adjustments, although expectancies seemingly did not do this in Experiments 1 and 2.

In the remainder of this article, we discuss two possible alternative accounts of our data, one in terms of feature priming (e.g., Hommel et al., 2004) and the other in terms of stimulus conflict evoked by our neutral stimuli (e.g., Verbruggen et al., 2006). We argue that the alternative accounts fail to account for critical aspects of the RT patterns that we observed. Next, we present a two-factor account of the Gratton effect and the underlying RT patterns in the literature and the present experiments, and we demonstrate the utility of this account through computer simulations. Finally, we discuss the consequences of our findings for the prevailing conflict-monitoring theory of the Gratton effect.

Two alternative accounts of the present findings

At first sight, two other explanations could be put forward for our data patterns, one concerning stimulus feature priming effects, and the second based on the neutral stimuli that we used. We discuss these alternative accounts below.

A feature-priming account

Experiments 1 and 2 indicated that the RT distractor effect does not differ following an incongruent and a neutral trial, whereas the distractors have a larger influence following a congruent trial. To make sure that this Gratton effect did not in fact stem merely from bottom-up stimulus

repetition priming effects, we reanalysed our data after removing all exact stimulus repetitions and showed that the Gratton pattern was still observed. However, we used a small stimulus set in both experiments (only two possible task-relevant stimulus values). As a result of this, the findings obtained could in principle be explained by a more complex form of repetition priming at the level of stimulus features (e.g., Hommel et al., 2004; Notebaert et al., 2001). Note that when the distractor type was repeated in two successive trials (i.e., cC, iI), either the complete stimulus was repeated (e.g., HSHH → HSHH), or both the distractors and the target were alternated (e.g., HSHH → SSHS). In contrast, when the compatibility was dissimilar in two successive trials (e.g., cI, iN, nC), the current stimulus contained always a partial repetition. That is, either the target was repeated combined with alternated distractors (e.g., HHHH → SSHS), or the target was alternated, and the distractors were repeated (e.g., HHHH → HSHH). Therefore, even when all exact stimulus repetitions are removed from analyses, as we did, the compatibility transitions in Experiments 1 and 2 are confounded with partial repetition/full alternation effects, and the two cannot be dissociated in the current set-up. Partial repetitions have been shown to be associated with relatively slow responses compared with full alternation trials (Hommel et al., 2004). Thus, the results of Experiments 1 and 2 cannot exclude the possibility that partial repetitions caused the responses to be slower for iC trials than for cC trials.

However, feature priming cannot account for the RT patterns that we observed. The feature-priming account predicts that RTs on trials with full alternations should be shorter than those on trials with partial repetitions. Thus, the account correctly predicts our finding that RTs on cC trials (full alternation) were shorter than RTs on cI trials (partial repetition), which is also illustrated in Figure 1A. However, for the same reasons, the account also predicts that iI trials (full alternation) should be faster than cI trials (partial repetitions), as illustrated in Figure 1A. However, this is clearly not what we observed, neither in

Experiment 1 (Eriksen) nor in Experiment 2 (Stroop). Thus, feature priming cannot account for the complete set of RT patterns that we obtained. It should be noted that we observed the same RT patterns in Experiment 3, where the adjustments were driven by symbolic cues preceding the target stimulus. This finding confirms the conclusion from Experiments 1 and 2 that our RT patterns are independent of feature priming (see Fernandez-Duque & Knight, 2008, for the same rationale). This conclusion is in line with several studies that controlled for feature priming effects and observed that these bottom-up factors could not account for the Gratton effect (e.g., Kerns et al., 2004; Notebaert et al., 2006; Ullsperger et al., 2005; Verbruggen et al., 2006).

A stimulus conflict account

A second alternative for our interpretation of the data in Experiments 1 and 2 involves the use of neutral stimuli. As pointed out by Eriksen and Eriksen (1974), the flanker task really entails two sources of conflict, one related to the stimulus itself (sometimes termed “stimulus conflict” or “perceptual conflict”, see, e.g., De Houwer, 2003; Notebaert et al., 2006; Sanders & Lamers, 2002; van Veen & Carter, 2005; Verbruggen et al., 2006) and one related to the responses (“response conflict”). In Experiment 1, the flankers within a neutral stimulus were not associated with an alternative response and should therefore not compete for target selection. But as the flankers were different from the central target character, they may indeed distract at a perceptual level, and it may well be that the stimulus conflict drives behavioural adjustments (Notebaert et al., 2006; Notebaert & Verguts, 2006; Verbruggen et al., 2006). Consequently, our neutral stimulus could be considered a “light variant” of an incongruent stimulus.

In examining effects of stimulus and response conflict in a flanker task, Verbruggen et al. (2006) had participants identify central target colour lines and ignore flanking colour lines by pressing corresponding response keys. Six colours were mapped onto three responses. Consequently, stimuli could be stimulus incongruent (i.e., central colour and flanker colours differed but were

mapped onto the same response), response incongruent (i.e., central colour and flanker colours differed and were mapped onto different responses), or congruent (i.e., central colour and flanker colours were the same). Verbruggen et al. observed that the magnitude of response conflict (i.e., different targets and flankers mapped onto the same versus different responses) did not depend on previous trial type (stimulus incongruent, response incongruent, or congruent). In contrast, stimulus conflict was obtained after a congruent trial but not after the other trial types. These findings suggest that adjustments may be driven by stimulus conflict, independent of response conflict. Verbruggen et al. (2006) discussed the possibility that their findings were specific to the arbitrary stimulus–response mappings used in their experiment. According to them, when other kinds of mappings are used, “it could be the case that participants deal with response conflict in a different way” (p. 332). The present Experiments 1 and 2 extend the study of Verbruggen et al. by examining the Gratton effect in more commonly used tasks—namely, Eriksen flanker and Stroop, and employing both arbitrary stimulus–response mappings (Eriksen flanker, manual Stroop) and nonarbitrary ones (vocal Stroop).

Possibly, the neutral condition in the present Experiments 1 and 2 was not really free of conflict but evoked stimulus rather than response conflict, like in the study of Verbruggen et al. (2006). The results of Experiments 1–2 would then provide converging evidence that in Eriksen and Stroop task performance, adjustments may be driven by stimulus conflict, independent of response conflict. It should be noted, however, that our neutral stimuli and the stimulus-incongruent stimuli of Verbruggen et al. differ in important respects, which complicates a direct comparison between studies. First, the flankers in the stimulus-incongruent condition of Verbruggen et al. occurred as targets on response-incongruent and congruent trials, which does not hold for the neutral stimuli in our Experiments 1–2. Second, the flankers in the stimulus-incongruent condition were mapped onto responses, whereas the Os (Eriksen task) or Xs (Stroop task) in our Experiments 1–2 were not.

Moreover, evidence suggests that our neutral stimuli (i.e., Os and Xs) do not really evoke (much) stimulus conflict. Roelofs, Van Turenout, and Coles (2006) had participants respond manually to the arrows or words of incongruent or congruent combinations of left- or right-pointing arrows and the words *left* or *right* in an fMRI experiment. Neutral stimuli consisted of arrows combined with Xs or words with empty rectangles. The experiment showed effects of response conflict in RTs and ACC activity in the word task, but no effects of stimulus or response conflict in the arrow task using Xs as neutral condition. This suggests that when distractors are not mapped onto responses, like the Xs, they do not yield conflict. Moreover, in a new experiment in our lab (Lamers & Roelofs, 2010) with 20 participants vocally responding in the Eriksen flanker task and the design of Verbruggen et al. (2006), we obtained evidence for response conflict (RT response-incongruent > RT stimulus-incongruent), $t(19) = -6.25, p < .001$, but not for stimulus conflict (RT stimulus-incongruent \approx RT congruent), $t(19) = 0.19, p > .85$. Thus, it is plausible to assume that the neutral stimuli in the present Experiments 1 and 2 do not really evoke (much) stimulus conflict.

Still, the RT patterns of the present Experiments 1 and 2 resemble in several ways the data obtained by Verbruggen et al. (2006), suggesting that the adjustments in the present experiments may nevertheless have been driven by stimulus conflict induced by our neutral stimuli. There is, however, also an important difference in RT patterns between studies that creates difficulty for a stimulus conflict account of the present data. Whereas Verbruggen et al. obtained the RT patterns illustrated in Figure 1A, we obtained the RT patterns of Figure 1B. In the experiment of Verbruggen et al., RTs were shorter on cC than on iC trials, and longer on cI than on iI trials, whereas this was not the case in our Experiments 1 and 2. The RT patterns of Verbruggen et al. are readily explained by adjustments driven by stimulus conflict, but our data are not. The presence of stimulus conflict on stimulus-incongruent and response-incongruent trials in the experiment of Verbruggen et al.

would lead to a narrowing of attention compared with congruent trials, and hence the distractor effect is smaller on the next trial. This explains why RTs were longer on response-incongruent and stimulus-incongruent trials when they followed congruent trials than when they followed response-incongruent and stimulus-incongruent trials. However, in our Experiments 1 and 2, the RTs on incongruent and neutral trials were not affected by the previous trial type. Thus, adjustment driven by stimulus conflict would explain why RTs are shorter on congruent trials for postcongruent than for postneutral and postincongruent trials. But for neutral and incongruent trials, it would predict longer RTs on postcongruent than on postneutral and postincongruent trials, contrary to what is obtained. In short, whereas adjustment driven by stimulus conflict would explain the data of Verbruggen et al., it cannot explain the present findings. What, then, does explain the RT patterns in our Experiments 1 and 2? A possible explanation is discussed next.

A two-factor account

The Gratton effect implies that the distractor effect is smaller for postincongruent trials than for postcongruent trials, but this effect can arise from several different underlying RT patterns, as illustrated in Figures 1A–1C. The canonical RT pattern obtained in several studies (e.g., Egner & Hirsch, 2005; Verbruggen et al., 2006) is shown by Figure 1A. In our experiments, for current-incongruent trials, the compatibility of the preceding trial had no influence (i.e., response times for cI, iI, and nI trials did not differ), which corresponds to Figure 1B. This data pattern was also obtained by Ullsperger et al. (2005) and Freitas et al. (2007) using a flanker task. Similarly, in a Simon task, Stürmer et al. (2002) found that the Simon effect occurs only following a congruent trial (but see Hommel et al., 2004, for a different interpretation of the results). In contrast, Kerns et al. (2004) observed that the response times on incongruent trials did differ following incongruent and congruent trials, whereas the compatibility of the preceding trial did not influence response

times on congruent trials, as illustrated in Figure 1C. These differences among studies cannot be due to the fact that most studies used manual responding, because we obtained our data patterns regardless of response modality. Also, it is unlikely that the differences are due to the used task (Eriksen versus Stroop), because we obtained our data patterns regardless of the task.

It seems to us that the various RT patterns can only be explained by assuming that two factors are at work (cf. Ullsperger et al., 2005). One factor (i.e., attentional width) causes the Gratton effect, which we take to be an effect of expectation (cf. Aarts & Roelofs, in press; Aarts et al., 2008). The other factor causes responding to be generally slowed following incongruent trials (slowing both iC and iI trials) or hastened following congruent trials (speeding up both cC and cI trials), which may fully or partially offset the effect of widening of attention on cI trials. For example, following incongruent trials, participants may be more cautious and adopt a more stringent response criterion (e.g., Meyer et al., 2003) or engage in more extensive self-monitoring (e.g., Roelofs, 2004) after response selection.

We tested the utility of this two-factor account (i.e., in terms of the factors attentional width and response caution) by running computer simulations using the WEAVER ++ model of performance in Stroop-like tasks (e.g., Roelofs, 2003; Roelofs et al., 2006). The model assumes that colours and words activate corresponding information in an associative network. The impact of distractor words in colour naming in the model is determined by several factors, including the attentional width, which corresponds to the duration of distractor input to the associative network. Computer simulations reported in Roelofs (2003) revealed that WEAVER ++ successfully accounts for several classic data sets on RT patterns in Stroop task performance, mostly taken from the review by MacLeod (1991). With only three free parameters, the model accounts for 96% of the variance of 16 classic studies (250 data points). Moreover, the model accounts for key findings on ACC activity in performing Stroop-like tasks, both with manual and with

vocal responding (e.g., Roelofs & Hagoort, 2002; Roelofs et al., 2006).

The computational protocol in the present simulations was the same as that in previous WEAVER ++ simulations of colour-word Stroop task performance (i.e., Roelofs, 2003; Roelofs & Hagoort, 2002). The parameter values were fixed and were identical to those in earlier simulations. The width of attention was simulated by manipulating the duration of distractor input in the model, which was set at 100 ms following congruent trials and 50 ms following incongruent trials. The postselection slowing caused by greater caution was set at 0, 25, or 50 ms. Figures 5A–5C show the simulation results. The results of applying only the attentional width manipulation in the model (i.e., zero slowing) are displayed in Figure 5C. A Gratton effect is obtained, which occurs because RTs on incongruent trials are longer following congruent than following incongruent trials, whereas RTs on congruent trials are not affected by previous trial type. This pattern of results corresponds to what Kerns et al. (2004) obtained for Stroop task performance. Kerns et al. suggested that congruent trials are not much affected by the width of attention, which holds for the model.

The simulations showed that greater caution in responding following incongruent trials (e.g., a more stringent response criterion or more extensive self-monitoring after response selection) may fully or partially offset the effect of the width of attention on cI trials. The postselection slowing caused by greater caution was set at 50 ms in Figure 5B and at 25 ms in Figure 5A. The RT patterns in Figure 5B correspond to those in the present Experiments 1 and 2, and the RT patterns in Figure 5A correspond to the canonical RT pattern. Note that the postselection slowing did not affect the Gratton effect (i.e., its magnitude is fully preserved), but only the underlying RT patterns.

To conclude, the simulation results demonstrate the utility of a two-factor account of the different patterns of RTs underlying the Gratton effect in the literature and the present experiments. The account assumes that expectations concerning

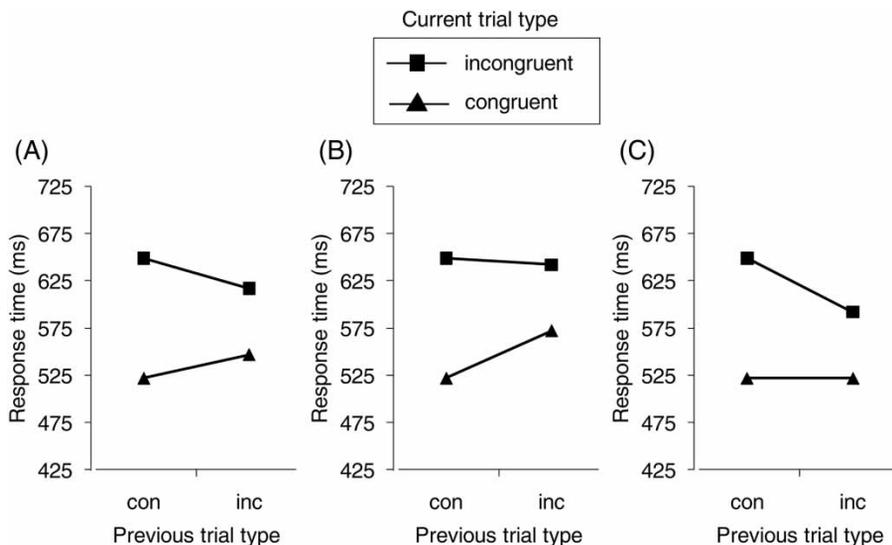


Figure 5. The effect of attentional width and response caution in *WEAVER ++* simulations. Shown are the mean response times for incongruent and congruent trials as a function of previous trial type (congruent, incongruent). Attention was set wider following congruent than following incongruent trials. Greater caution after incongruent trials was set to offset partially (A), fully (B), or not at all (C) the effect of attentional width on incongruent trials following congruent trials.

upcoming trial types determine the attentional width (cf. Aarts & Roelofs, in press; Aarts et al., 2008), whose effect may be modified by differences in caution in responding depending on trial type.

Consequences for the conflict-monitoring hypothesis

Botvinick et al. (2001) took the Gratton effect as evidence for conflict adaptation in task performance. These researchers have built an extensive theory of attention adjustments around such conflict adaptation (e.g., Botvinick et al., 2001; Botvinick, Cohen, & Carter, 2004; Carter et al., 1998; Carter et al., 2000; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001; Yeung et al., 2004), which has become the dominant theory in the literature. As mentioned earlier, the idea is that if participants detect response conflict on incongruent trials, they engage more attentional control to be prepared for conflict on the subsequent trial, which reduces the effect from the distractors. We questioned the idea that the presence of response conflict is really necessary for the

Gratton effect to emerge (likewise, recent expansions of the original conflict monitoring theory allow for the possibility that conflict may arise at other levels of information processing than response conflict, cf. Botvinick, 2007). Our data patterns of Experiments 1 and 2 indicate that the effect that an incongruent stimulus has on the next trial is, in fact, not different from the effect that a neutral stimulus has. This strongly suggests that in these experiments the adjustments in attention were independent of response conflict. The observed absence of a difference in distractor effect for postincongruent and postneutral trials in the present study poses a challenge for the conflict monitoring theory (Botvinick et al., 2001; Yeung et al., 2004).

Our finding that sequential modulations of control can be independent of conflict in Eriksen and Stroop task performance is in line with other recent observations. Burle et al. (2005) measured electromyographic activity in the Simon task. On some congruent trials, activation of the incorrect response led to motor activity, and therefore these trials can be classified as response conflict

trials. However, no adaptation effects were observed following such a trial. Moreover, Notebaert and Verguts (2006) demonstrated that not response conflict, but stimulus conflict may trigger the modulations. Together, these findings suggest that (a) response conflict is not necessary for adaptation effects to occur, and (b) response conflict is also not sufficient for such attentional control adjustments.

Recently, Botvinick (2007) suggested that control adjustments are driven by experienced or expected effort. Effort is greater for incongruent than congruent trials, explaining the control adjustments. However, an fMRI study in our lab (Aarts et al., 2008) observed that control adjustments can be independent of expected effort based on cues. In the present experiment, experienced effort will have been larger following incongruent than following neutral trials, as is evident from the difference in RTs and errors. Still, the distractor effect did not differ following incongruent and neutral trials. Moreover, in Experiment 3, incongruent-predicting cues suggest more effort than neutral cues, but control adjustments did not differ between these cues types. Thus, effort-based adjustment cannot account for our data.

CONCLUSIONS

The results of Experiments 1 and 2 indicate that the RT difference between incongruent and congruent trials is larger after congruent trials than after incongruent and neutral trials, with the latter two yielding the same RT difference. This pattern of results suggests that control adjustments may be independent of response conflict, contrary to what the conflict adaptation hypothesis holds. Moreover, RTs on incongruent trials were not affected by the previous trial type, contrary to what the expectation hypothesis predicts. However, RTs on both congruent and incongruent trials were affected when expectancies were explicitly manipulated by symbolic cues in Experiment 3, indicating a role for expectations. We presented a two-factor account of the various RT patterns underlying the Gratton effect observed in the

literature, including the RT patterns of the present experiments, and demonstrated the utility of this two-factor account using computer simulations. Theories of attentional control (e.g., Botvinick et al., 2004; Botvinick et al., 1999; Miller & Cohen, 2001; Yeung et al., 2004) require modification to include consideration of our findings.

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