Sustained vs. transient cognitive control: Evidence of a behavioral dissociation

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ABSTRACT

This study assessed whether two well known effects associated with cognitive control, conflict adaptation (the Gratton effect) and conflict context (proportion congruent effects), reflect a single common or separate control systems. To test this we examined if these two effects generalized from one kind of conflict to another by using a combined-conflict paradigm (involving the Simon and Spatial Stroop tasks) and manipulating the proportion of congruent to incongruent trials for one conflict (Simon) but not the other (Spatial Stroop). We found that conflict adaptation effects did not generalize, but the effect of conflict context did. This contrasting pattern of results strongly suggests the existence of two separate attentional control systems, one transient and responsible of online regulation of performance (conflict adaptation), the other sustained and responsible for conflict context effects.

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1. Introduction

In order to understand how we can operate efficiently in complex environments, it is important to understand how cognitive control can be affected over pre-potent responses. A popular means to examine cognitive control has been to use interference tasks, where two different processing streams compete for behavior, with often the response being required to the stimulus with a less potent stimulus–response mapping. One example of this is the Stroop color-naming task (for a review see Macleod, 1991), where larger reaction times (RTs) are systematically found for trials where the name of the printed word is incongruent with its color (e.g., naming the color of a word printed in green ink when the word is "RED"), compared with when the name and the color are congruent (the word "RED" printed in red ink). To ensure that color rather than word naming takes place, it is typically assumed that some

form of cognitive control has to overrule the tendency for participants to read the word, but this is at a cost to RTs (Cohen, Dunbar, & McClelland, 1990).

To study how control processes operate in tasks such as Stroop color-naming, experimenters have manipulated the proportion of congruent to incongruent trials occurring in a block. The magnitude of the congruency effect varies with the proportion of congruent trials, being larger within a context on a high proportion of congruent trials and smaller within a context on a high proportion of incongruent trials (e.g., Carter et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). This modulatory effect is most commonly attributed to the adoption of a *sustained* strategy or task set probably implemented after having experienced the level of conflict encountered on the first few trials in a block. This task set produces tonic changes in processing by (e.g.) altering the 'weighting' of word-reading relative to color-naming (e.g. Cohen et al., 1990; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). When there is a high proportion of congruent trials (in a low conflict

context), participants may allocate word-reading a relatively strong weighting, since it often leads to the correct response. This leads to fast responses on congruent trials and large interference effects on incongruent trials. In contrast, when there is a low proportion of congruent trials (i.e., in a high conflict context) processing may be weighted towards the weaker stimulus–response mapping, reducing the effects of the word on color-naming (generating a smaller congruency effect). This switching of weights between different stimulus–response mappings effects a form of sustained cognitive control over performance.

However, more *dynamic* forms of control can also be implemented. Such dynamic modulation is indicated by findings demonstrating that the congruency effect on a given trial can be dramatically affected by the level of interference encountered on the preceding trial. In particular, there is a reduced congruency effect on the current trial (*N*) when the stimulus on trial *N* − 1 was also incongruent. This dynamic trial by trial modulation is generally known as the 'conflict adaptation' or Gratton effect (Gratton, Coles, & Donchin, 1992). Based primarily on neuroimaging, this effect has been decomposed into two main processes: (i) conflict monitoring, triggered by the dorsal anterior cingulate cortex (dACC), and (ii) control recruitment (on incongruent trials) mediated though the dorsolateral prefrontal cortex (DLPC). According to this account, a conflict between two competing stimulus–response mappings would be monitored (via the dACC) and, on incongruent trials, resources would be recruited through the DLPC in order to reduce the influence of irrelevant information. This transient process then influences performance on the next trial; in particular, interference effects are reduced when the immediately following trial is also incongruent (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter et al., 1998, 2000; Casey et al., 2000; Egner & Hirsch, 2005; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000).

Although we may speculate that the processes that generate cognitive control under conditions of conflict context (the proportions of congruent to incongruent trials) have a different time course than those responsive to 'conflict adaptation, the exact relations between these effects remains unresolved. One possibility is that the effects of the conflict context may depend on the same transient control mechanism responsible for conflict adaptation effects. For example, in the context of a high proportion of incongruent trials, the relatively fast RTs on incongruent trials could be due to the large number of trials where conflict adaptation takes place (when the prior trial is incongruent). In contrast, the increased congruency effect when congruent trials are likely may be because conflict adaptation rarely takes place. A second possibility is that conflict context effects rely on a separate process acting proactively and producing sustained changes in the weights on different stimulus–response mappings.

Evidence favoring the existence of two separate mechanisms for the effects of conflict context and conflict adaptation would arise from a behavioural dissociation between the effects. Recent research reveals that one main property of conflict adaptation effects is that they can be very specific to the kind of conflict encountered on the previous trial (Egner, Delano, & Hirsch, 2007; Fernández-Duque & Knight, 2008; Funes, Lupiáñez & Humphreys, in press; Kiesel, Kunde, & Hoffmann, 2006; Notebaert & Verguts, 2008, condition 2; Verbruggen, Liefooghe, Notebaert, & Vandierendonck, 2005, Experiment 2; Wendt, Kluwe, & Peters, 2006). Thus, a change across consecutive trials in the type of conflict present can completely eliminate conflict adaptation (e.g. when trial *N* − 1 involves stimulus or Stroop-type congruency and trial *N* response or 'Simon'-type congruency). Interestingly, this pattern of specificity arises even when the very same stimuli and responses are used for both types of conflict types (Egner et al., 2007; Funes et al., in press; Wendt et al., 2006). This wide set of studies clearly indicates that there is no transfer or generalisation of conflict adaptation across different types of conflict (see Egner (2008), for a recent review on this literature).

In the present study we examine whether the same conflict type of specificity holds for the effects of conflict context. To assess this, we used conditions in which a spatial version of Stroop and Simon-types of congruency were combined within a trial block. Participants responded to the up or down direction of an arrow using left or right response keys. In the Simon conflict type, interference arises from a conflict between the spatial location of the stimulus (left or right from fixation) and the required (left or right) response (S–R interference). In the Spatial Stroop, interference arises from a conflict between the spatial location of the stimulus (up or down from fixation), and its up or down direction (S–S interference). Critically, we varied the proportion of congruent to incongruent trials in just one conflict type. We test whether there are effects of conflict context not only for the type of congruency on which the proportion of congruent trials was manipulated, but also for the other type of congruency effect (where there were equal numbers of congruent and incongruent trials). In conjunction with this, we also evaluated whether effects of conflict adaptation showed no generalisation. Finally, the kind of stimuli, the nature of the task and the required responses were kept constant across conflict types (so there were no task switches). Evidence for conflict type generalisation for one effect but not the other would support the argument for independent mechanisms being involved in generating cognitive control.

1.1. Method

1.1.1. Participants

Twenty-two undergraduate psychology students from the University of Birmingham and the University of Granada participated in the experiment. Their ages ranged from 18 to 34 years, with a mean age of 22.27. All had normal or corrected to normal color vision and were naïve as to the purpose of the experiment. They all participated voluntarily and received credits from their Psychology course.

1.1.2. Apparatus and stimuli

Participants were tested on a Pentium computer running E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). The stimuli were presented on a 14-in. color Samsung monitor. Subjects sat in front of the computer's

screen at a viewing distance of about 53 cm. All the stimuli consisted of black arrows pointing either up or down, and subtending 0.54° of visual angle in width and 1.08° in length. The target could appear in one of four possible locations, to the left, right, above or below fixation (a plus sign in the center of the screen), at one of the four vertices of an imaginary diamond. These four locations were equidistant to fixation (4.32°). Responses were made by pressing either the "v" key (left response) on the keyboard with the index finger of the left hand or the "m" key (right response) with the index finger of the right hand.

1.1.3. Procedure

Participants were instructed to make left/right keypresses in response to the up/down direction of the arrow. Half the participants responded to the "up" direction by pressing the letter "V" (left response) with the index finger of their left hand and to the "down" direction by pressing the letter "M" (right response) with the index finger of their right hand. The opposite mapping was used for the other participants. The participants were also informed that the target could appear with equal probability in one of four possible locations, left, right, above or below fixation. The instructions stressed the need to respond as fast as possible while trying to avoid errors. Participants were asked to maintain fixation at the center of the screen before the target was presented. The sequence of events on each trial was as follows: The fixation point was displayed for 750 ms. After this, the target was displayed for 200 ms, and the fixation point remained alone in the screen until the participants' response or for 2000 ms if there was no response. The intertrial interval was 1500 ms and during that time the screen remained empty. Auditory feedback (a 2000 Hz, 50 ms computer-generated tone) was given on error trials. The trials were grouped in blocks and presented randomly in each block. The experiment stopped between blocks. Participants were instructed to rest a few seconds between blocks; following this they re-started with the experiment by pressing the space bar.

1.1.4. Design

Three within subjects variables were manipulated. The first variable was *conflict type*, which took two possible values, S–S Spatial Stroop, where the target appeared on the vertical axis, and S–R or Simon, where the target appeared on the horizontal axis. The second variable was *congruency*, which took one of two values, congruent trials, when the arrow location corresponded with the arrow direction (in the case of Spatial Stroop stimuli) or whenever the arrow location was corresponding with the response location (in the case of Simon stimuli). Incongruent trials were defined as those where the arrow location did not correspond with the arrow direction or the response location. The third variable was *conflict context*, which also took two levels, the high conflict condition and low conflict condition. This variable was manipulated between blocks and was presented in an ABBA order. In each block half of the trials were Simon stimuli and the other half were Spatial Stroop stimuli. In the low conflict condition, 62.5% of the trials were congruent and 37.5% were incongruent, while high conflict blocks consisted of 37.5% congruent and 62.5%

incongruent. Critical to the aim of the study was that this proportion congruent manipulation did not apply equally to both types of conflict. In the low conflict condition, 75% of Simon trials were congruent, while 25% where incongruent; in the high conflict condition 25% of Simon trials were congruent, while 75% where incongruent. However, for trials with Spatial Stroop congruency, there were equal proportions of congruent and incongruent trials for both the low and the high conflict conditions.

In addition to these three variables, we recoded offline sequential effects by creating two additional variables. One variable was created to code the level of congruency encountered on the previous trial, the *previous congruency* variable (this too took two levels, congruent and incongruent). The fifth variable was *conflict type shift*, which coded whether the type of conflict encountered on the current trial constituted a repetition or an alternation of the kind of conflict encountered on the previous trial. Conflict repetition trials consisted of any Spatial Stroop trial followed by another Spatial Stroop trial (both appearing along the vertical axis), or a Simon trial followed by another Simon one (both appearing along the horizontal axis). Conflict alternation trials consisted of any Spatial Stroop trial in the vertical axis preceded by a Simon trial in the horizontal axis or vice versa. These five variables led to 32 experimental conditions from the combination of conflict type (2, Spatial Stroop vs. Simon) × congruency (2, congruent vs. incongruent) × previous congruency (2, congruent $N - 1$ vs. incongruent $N - 1$) × conflict type shift (2, conflict type repetition vs. conflict type alternation), and conflict context (2, low conflict, high conflict). Participants performed a block of 16 practice trials which were excluded from the analysis, followed by 20 blocks of 32 experimental trials each.

2. Results and discussion

A repeated measures analysis of variance (ANOVA) was conducted on mean RTs. The first trial of each block, error trials and trials following an error were excluded from the analysis. This procedure excluded 14.9% of the trials. RTs shorter than 200 and longer than 1200 ms were also excluded. This cut-off procedure excluded less than 1% of the remaining trials. The variables conflict context, conflict type, congruency, previous congruency and conflict type shift were included as within subjects. (See Fig. 1)

We found a main effect of congruency, $F(1, 21) = 94.33$, $p < .00001$, with RTs being faster for congruent (516 ms) than for incongruent trials (547 ms), as well as a main effect of conflict type, $F(1, 21) = 18.97$, $p > .0005$, with faster RTs for Simon (526 ms) than for Spatial Stroop stimuli (537 ms).

Given that we verified an effect of congruency, we subsequently simplified the analysis in an (ANOVA) with the variables conflict context, conflict type, previous congruency and conflict type shift included as within participants factors, with the congruency effect (computed as the difference between the congruent and incongruent conditions) taken as the dependent variable (see Table 1 for the mean RT data).
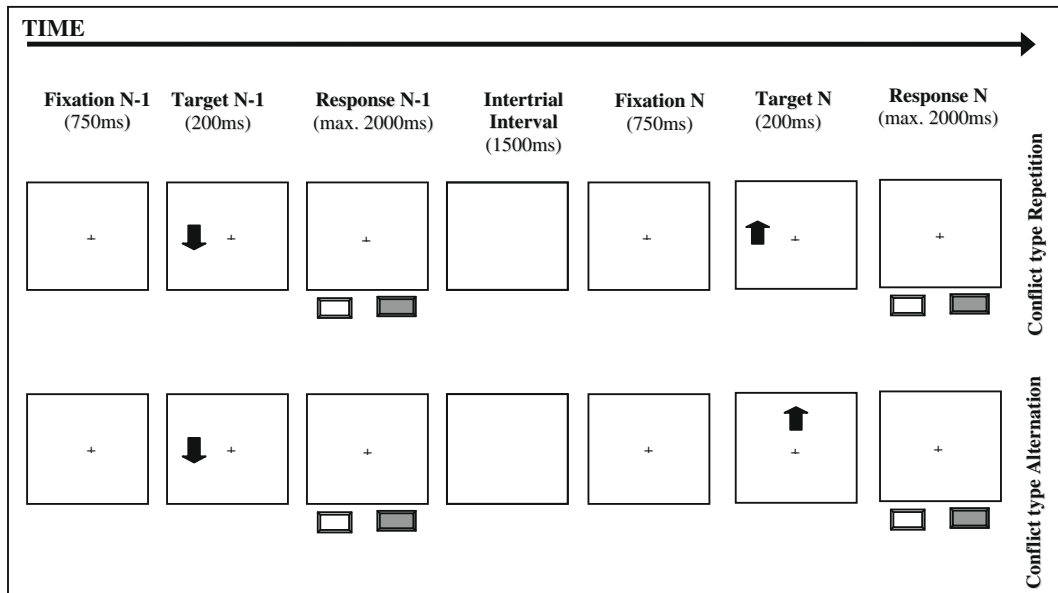
Fig. 1. Sequence of events on two consecutive trials. The upper panel represents an example of the conflict type repetition condition, where a Simon stimulus on trial N − 1 is followed by a second Simon stimulus on trial N. The lower panel represents an example of the conflict type alternation condition, were a Simon stimulus on trial N − 1 is followed by a Spatial Stroop stimulus on trial N.

Table 1
Mean RTs per experimental condition.

| Conflict context	Conflict type	Conflict type alternation				Conflict type repetition			
		N − 1	C		I		C		I
		N	C	I	C	I	C	I	C	I
Low conflict	Simon		502	541	502	560	477	559	512	547
	Spatial Stroop		521	565	516	563	494	555	541	542
High conflict	Simon		515	537	522	539	510	550	517	520
	Spatial Stroop		543	552	526	554	514	550	537	523

2.1. The conflict adaptation effect

We found a significant influence of congruency on the previous trial ($F(1, 21) = 11.38$, $p = .005$) and a highly reliable interaction between previous congruency and conflict type shift, $F(1, 21) = 29.38$, $p < .0001$. Planned comparisons revealed the typical Gratton effect for the conflict type repetition condition, for which there was a significant effect of previous congruency, $F(1, 21) = 39.53$, $p < .0001$ (see Fig. 2, right panel). There was a large conflict effect on the current trial when trial N − 1 was congruent (55 ms), while this was drastically reduced when trial N − 1 was incongruent (6 ms, $F < 1$.). In contrast, the analysis conducted on the conflict type alternation condition revealed a null effect of congruency on the prior trial ($p = .3$). In sharp contrast to the conflict type repetition condition, the Gratton effect was completely absent when the conflict type alternated (from Spatial Stroop to Simon, or vice versa; see Fig. 2, left panel).

This pattern of results generalizes the findings from previous studies where different combined-conflict paradigms were used (Egner et al., 2007; Funes et al., in press; Kiesel et al., 2006; Notebaert & Verguts, 2008, condition 2; Verbruggen et al., 2005, Experiment 2; Wendt et al., 2006). It strongly supports the view that the transient (trial by trial) control process that generates the Gratton effect is specific to the type of conflict dealt with in the previous trial. Consequently, a shift towards a different source of conflict completely eliminates any recruitment of resources to deal with an incongruent event. This specificity occurred even though we kept constant the type of task and the type of stimuli across consecutive trials.

2.2. The conflict context effect

We found only a main effect of conflict context, $F(1, 21) = 23.28$, $p < .0005$. There was a drastic reduction in the congruency effect when there was a high likelihood of incongruent trials (18 ms) compared to when there was a high likelihood of congruent trials (46 ms). Critically, there was no hint of a two-way interaction between con-
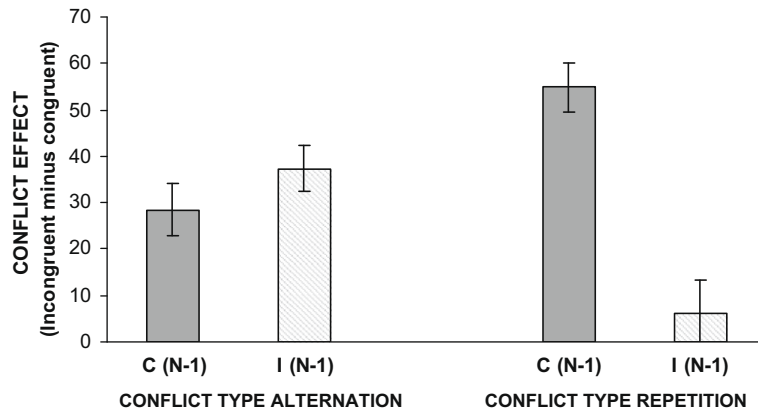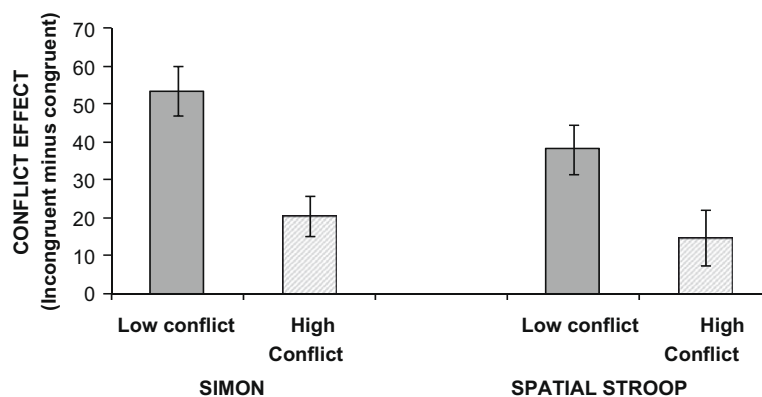
Fig. 2. Conflict effect (difference between mean RT for congruent and incongruent conditions in the current trial), as a function of previous congruency ($N-1$). The left panel shows the effect of congruency on the previous trial for the condition with alternating type of conflict and the right panel shows the effects of congruency when the type of conflict was repeated.

flict context and conflict type ($F < 1$). Thus, even though conflict context was exclusively manipulated for Simon stimuli (and there were equal proportions of congruent to incongruent trials for Spatial Stroop trials), the reliable effect of repeating the conflict context was not modulated by varying the type of interference. To test this further, we conducted separate ANOVAs on each conflict type. For trials with Simon-type congruency, there was the standard effect of conflict context, $F(1, 21) = 20.23$, $p < 0.005$, with a larger conflict effect when incongruent trials were unlikely (53 ms) compared to when incongruent trials were likely (20 ms), see Fig. 3 left panel). More importantly, there was similar effect of conflict context on Spatial Stroop stimuli, $F(1, 21) = 6.75$, $p < 0.05$, with a substantial congruency effect when congruent trials were likely (38 ms) and a smaller effect when incongruent trials were likely (15 ms, see Fig. 3 right panel).

Finally, it is noteworthy that there was a null interaction between conflict context and previous congruency ($F < 1$), which may be interpreted as an index of additivity between these two factors.

3. General discussion

The pattern of results obtained in the present study provides novel evidence for a behavioural dissociation between two factors that modulate interference effects from pre-potent responses to stimuli – the conflict adaptation and conflict context effects. We confirmed that conflict adaptation was highly specific to the type of conflict encountered on the previous trial. This replicates recent findings which have combined different conflict paradigms (Egner et al., 2007; Fernández-Duque & Knight, 2008; Funes et al., in press; Verbruggen et al., 2005, Experiment 2; Wendt et al., 2006, see Egner (2008) for a recent review). The conflict adaptation effect does not generalize across different types of congruency. On the other hand, we found that the effects of conflict context did generalize across conflict types. There was a significant effect of conflict context on Stroop-type congruency even when the proportion congruent manipulation only took place for the Simon-type congruency. In addition, the effects of conflict context combined additively with the effects of prior congruency.

Fig. 3. The conflict effect (the difference between mean RTs for the congruent and incongruent conditions), as a function of conflict context. The left panel shows the conflict context effects for Simon stimuli and the right panel shows conflict context effects for Spatial Stroop stimuli.

These contrasting generalisation effects are difficult to explain if there is a common control mechanism responsible for both the conflict context and the conflict adaptation effects. However, these data are consistent with there being separate control systems underlying the two effects.

3.1. The mechanisms of cognitive control

Apart from highlighting a behavioural dissociation between conflict context and conflict adaptation, the pattern of results obtained in the present study is helpful to understand the mechanisms underlying these two forms of cognitive control.

The pattern of conflict type specificity on the conflict adaptation effect is not consistent with the idea that a top-down centralized control mechanism is recruited to resolve all forms of conflict through a process of conflict adaptation. If that were the case, once activated after conflict detection, it should be able to produce conflict adaptation for the next trial, independently on whether it involves or not the same type of conflict to the one encountered in the previous trial.

That pattern of results regarding conflict adaptation could favour instead an automatic or bottom-up mode control in terms of feature repetition priming. According to some authors, conflict adaptation effects are suggestive of a form of control based on the repetition of particular stimulus features (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Notebaert, Soetens, & Melis, 2001). Based on their view, the usual benefit found for congruent–congruent (CC) and incongruent–incongruent (II) transitions in a trial series reflects repetition priming as the consecutive trials typically have identical stimuli, while this possibility is absent for congruent–incongruent (CI) and incongruent–congruent (IC) transitions. In our combined-conflict paradigm, feature repetition priming might contribute differentially to the contrast between conflict type alternation vs. repetition trials. Here there was an exact repetition of both the direction and location of the target arrow on half of the trials for CC and II transitions, while there was always a change in the arrow's location on trials where the conflict type alternated. Consequently, the lack of conflict adaptation found when the conflict type alternated could be due to a lack of benefit from feature repetition priming. To test this possibility, we ran a separate ANOVA with the variables being previous congruency and conflict type switch as within participants variables, but now excluding trials with exact S–R repetitions from the analysis (Kerns et al., 2004; Ullsperger, Bylsma, & Botvinick, 2005; Wühr & Ansorge, 2005). As before, we found a significant interaction between previous congruency and conflict type switch, $F(1, 21) = 5.76$, $p < .05$. Planned comparisons revealed the typical Gratton effect when the conflict type was repeated, with there being a significant effect of previous congruency, $F(1, 21) = 5.02$, $p < .05$. There was a large conflict effect on the current trial when trial $N - 1$ was congruent (44 ms), while this was reduced when trial $N - 1$ was incongruent (23 ms). In contrast, the analysis on trials where the conflict type alternated revealed a null effect of previous trial congruency ($F < 1$).

This analysis indicates that stimulus repetition priming is not the key source of the conflict adaptation effect found in the conflict type repetition condition in the general analysis. In addition, the finding generalizes the results obtained in other studies when using different conflict paradigms and where exact repetitions were also excluded from the analysis (Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Ullsperger et al., 2005). We conclude that the lack of conflict adaptation found in the general analysis when the conflict type alternated was not due to the exclusive absence of repetition priming in that condition.

However, one could still argue that, according to the feature integration hypothesis (Hommel et al., 2004), not only complete repetitions but also complete S–R alternations might be responded to more rapidly than partial repetitions. Because the remaining CC and II trials (after removal of complete repetition trials) in the conflict type repetition condition were necessarily complete alternations, while CI and IC trials consisted obligatory of partial repetitions, the previous analysis cannot completely rule out the possibility of some influence of feature integration in the present results.

This issue has been addressed in a recent study in our lab (Funes et al., in press). In that study, we compared a situation where only one source of conflict was present (Experiments 3 and 4 where all transitions were repetitions of Spatial Stroop-type of conflict) with a situation where two sources of conflict where combined (Spatial Stroop vs. Flankers in Experiment 1, and Spatial Stroop vs. Simon in Experiment 2 – an identical situation to the present study except for the conflict context manipulation, which was absent there). Apart from varying whether there were one or two sources of conflict, the two situations were equated for feature repetition priming and feature integration, as the axis on which the stimuli appeared could either repeat or alternate in a similar manner. More concretely, in Experiment 3, a Spatial Stroop arrow pointing left/right requiring a left/right response could appear in four possible locations (up-left, up-right, down-left, down-right). Consequently, in this case, there was always repetition of the same type of conflict, even when the stimuli shifted in their location along a main axis of the display (top–bottom). Similarly to the present results, when two sources of conflict were combined (Experiments 1 and 2) no conflict adaptation effects were found for the conflict type (and axis) alternation condition. However, when a single source of conflict was used, normal conflict adaptation effects were obtained for both the axis repetition and the axis alternation conditions. That paradigm also allowed us to analyze, separately, those sequences where at least one dimension repeated (exact repetitions and partial repetitions) and those sequences with complete alternations. That demonstrated that there was a normal conflict adaptation effect not only when feature repetitions were included but also when we considered only data from complete alternation trials (Funes et al., in press). This indicates that, within this version of the Spatial Stroop task, conflict adaptation effects can be genuine. In a final experiment (Experiment 4, Funes et al., in press) we used a joystick so that participants made up-down-left-right re-

sponses to the up-down-left-right direction of the arrow appearing at up-down-left-right locations. Note that in this case the direction of the arrows was left-right in the horizontal axis, but up-down in the vertical axis. Therefore, no dimension (either the stimuli or the responses) repeated in the axis-shift condition (all transitions constituted complete alternations). Here again a normal conflict adaptation effect was obtained (see also Kunde & Wühr, 2006, for similar data from a different paradigm).

Altogether, we propose that the evidence indicates that stimulus-specific repetition priming or feature integration seems not the key source of the present and previous response conflict and adaptation effects, at least with the present paradigm; rather, repetition of conflict type seems critical.

3.2. Relations to the wider literature

Our finding, that conflict adaptation is specific to conflict type, can be considered at odds with some recent studies that have reported a pattern of generality of conflict adaptation across conflict types (Kunde & Wühr, 2006; Notebaert & Verguts, 2008, condition 1; Freitas, Bahar, Yang, & Banai, 2007). However, as described further elsewhere (Funes et al., in press) one of the reasons why transfer of conflict adaptation may have been observed across conflict types is that the sources of conflict used in those experiments were similar in terms of dimensional overlap. For example, in the study of Notebaert and Verguts (2008) a Simon and SNARC effects were combined. These two forms of conflict might arise from the same kind of dimensional overlap (the overlap between the activation of an irrelevant target location representation and the response location; in both cases a type 3 situation according to Kornblum & Lee, 1995; Kornblum, 1992, 1994). Under these circumstances a common control system may be recruited to deal with both sources of conflict. In contrast, with our paradigm we ensured that the two types of conflict differed in terms of dimensional overlap. Following the taxonomy introduced by Kornblum (Kornblum, 1992, 1994; Kornblum & Lee, 1995), a conflict situation can be defined with regard to the kind of dimensional overlap that takes place between the relevant and the irrelevant dimensions of stimuli. Consequently if one conflict is caused by the overlap between two stimulus dimensions (as is the case for the present Spatial Stroop stimuli, where there is overlap between the two stimulus dimensions, the relevant direction and the irrelevant location), but another by overlap between the irrelevant stimulus location and the response location (as is the case for our Simon-like stimuli), then these two situations may be considered as intrinsically different (according to Kornblum's taxonomy our Stroop-like condition reflects a type 4 situation, while our Simon-like condition reflects a type 3 situation). Our results show that, under these conditions conflict adaptation cannot transfer from one type of conflict to the other even if the tasks have the same relevant target dimensions, type of stimuli and set of responses.

Our argument that repetition of the type of congruency is critical to conflict adaptation implies that at least partially separate systems might be recruited to generate transitive changes in processing according to the type of congruency involved. There are supportive data from functional brain imaging. There are several fMRI studies combing S–S or Stroop-type conflict with S–R or Simon-type conflict within the same task, that have found dissociations consistent with there being different control processes dealing with these two different forms of conflict. For example, in the study of Liston, Matalon, Hare, Davidson, and Casey (2006), activity in the ACC but not in the DLPFC or the dorsal PPC was sensitive to conflict at the level of the response, whereas activity in the DLPFC and the dorsal PPC but not the ACC was sensitive to conflict at the level of the stimulus representation. Egner et al. (2007) further showed that control-related activation in the superior parietal cortex specific to the resolution of stimulus-level conflict in the Stroop test, while control-related activation specific to the resolution of response-level conflict in the Simon test was found in the ventral premotor cortex. Third, Liu, Banich, Jacobson, and Tanabe (2004) found evidence of common brain activations for Spatial Stroop and Simon trials (dorsolateral prefrontal cortex, and middle occipital and inferior temporal cortices), but the authors also highlighted the existence of specific brain regions activated for each kind of conflict. Brain regions significantly more activated by the Simon task were the anterior cingulate cortex, supplementary motor areas, the precuneus and visuospatial motor association areas – regions associated with response suppression. In contrast regions significantly more activated by Stroop stimuli have been linked to biasing processing toward task-relevant attributes (the inferior parietal cortex).

In sum there is behavioural and neuroimaging evidence of important dissociations between control processes linked to different conflict types. This evidence strongly favors the view of domain specific control systems, specialized in detecting and/or solving different types of conflict (see Egner (2008), for a review). One hypothesis is that each of these control systems could have a similar structure to the one proposed by Botvinick and colleagues (2001) involving a conflict detector module connected to a conflict resolution module. The difference would be that, instead of proposing a single domain-general system, we argue that different conflict detectors/resolution systems co-exist, specialized in detecting conflict at different levels, and implementing control by different means (e.g., by target amplification or distractor inhibition). The dynamics of this mode of control could be congruent with what we refer as "mental inertia": Activation of one module, when one type of conflict is encountered, prepares the system to solve the same type of conflict in the next trial. However, if the next trial presents a different type of conflict, then the already activated module might be committed so that another control module needs to be committed. Thus, imagine the occurrence of a S–S conflict trial (e.g. incongruent Spatial Stroop). In this case there might be activation of a S–S conflict detector which might send a signal to an S–S conflict resolution module to implement control by, let say, target amplification. Consequently, if another S–S conflict situation occurs afterwards, the conflict resolution module would be already primed to implement control and the typical Gratton effect would arise. However,

if the second trial is incompatible but at the response-level (e.g. a Simon situation), the previous activation of the S–S conflict resolution system might not help to either detect or solve the new kind of conflict and a new process would need to be initiated. In this case there would be no conflict adaptation (conflict type alternation condition in our study).

In contrast to the arguments concerning conflict adaptation, the present evidence for the effects of conflict context generalizing across conflict type is consistent with a mode of control that is top-down and sensitive to the global amount of conflict encountered within a block. For example, once a given task set is implemented proactively early-on during a trial block, there may be sustained changes in the relative influence of irrelevant and relevant stimulus dimensions on performance. This process is not linked to a specific type of congruency but generalizes from one type of congruency to another. It is noteworthy that in our study, the target relevant information (the arrow direction) was kept constant across the different types of conflict. This suggests that the putative top-down mechanism for implementing conflict context effects operates by enhancing the processing of the relevant target information.

It might be argued that the conflict context effect on trials with Simon congruency could be explained in terms of conflict adaptation, given that there were different proportions of trial type transitions for the high and low conflict contexts in this case. However, this account cannot apply to the effects of conflict context found on Spatial Stroop stimuli. For these stimuli the proportions of transitions between trial types were the same across the context conditions (since the context varied only on trials where Simon stimuli were used). This again indicates that the effects of conflict context are separable from those of conflict adaptation.

Finally, it is worthy to note the differences between the pattern of generality in conflict context found in the present study when shifting across conflict types, with recent findings reporting specificity in conflict context when shifting across tasks and/or stimulus dimensions but keeping constant the type of conflict (Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006; Crump, Vaquero, & Milliken, 2008; Fernández-Duque & Knight, 2008; Jacoby, Lindsay, & Hessels, 2003). For example, in Fernández-Duque and Knight's study (2008), participants responded to two different kinds of Stroop stimuli, color Stroop or number Stroop. In addition to that, each task type was associated to a different proportion of congruent trials. These authors reported that conflict context effects did not generalize across tasks, and a pattern of conflict context specificity was obtained instead. In contrast, in Corballis and Gratton (2003) and Crump et al. (2006, 2008), a single type of conflict/task occurred on all trials. However, similar to our study, different target locations were systematically linked to different proportions of congruent trials. Once again, the modulation of color Stroop interference by the proportion of congruent trials was location specific (it depended on the proportion of congruent trials occurring at each location). Why should we have obtained a different result? One possible explanation for the pattern of specificity in

conflict context found in those studies might come from the fact that proportion congruent effects are more sensitive to shifts in the stimulus dimensions than conflict adaptation effects are (see Blais, Robidoux, Risko, and Besner (2007), for a review). It is possible that when two different proportion congruent contexts are made sufficiently different or salient in terms of stimulus dimensions, then participants may be sensitive to this correspondence, thus preventing a pattern of generalization across stimuli, tasks or conflict types. For example, in Corballis and Gratton (2003) and Crump et al. (2006, 2008) studies, the target could appear in two possible locations, each one systematically associated to either a high or low proportion of congruent trials. On the other hand, in our study, the stimuli could appear in four possible locations, two of them (within the horizontal axis) associated to a high/low proportion of congruent trials, and the other two locations associated to a context of 50% congruent trials (within the vertical axis). Based on that, it is possible that the pattern of location specific proportion congruent effects found in those studies is due to the fact that differences between the two contexts were made much more salient compared to our study where the use of four locations might have prevented the representation of clearly different contexts. A related explanation could be applied to account for the pattern of specificity in conflict context found in Fernández-Duque and Knight (2008), where the two kinds of stimuli associated to each conflict context were completely different to each other in both the relevant and the irrelevant dimension. This situation might have prevented the generalization of conflict context from one task to the other. Another possibility is that the proportion of congruent trials cannot generalize from one type of stimulus to the other because a task switching situation arises where the same set of responses is associated to different relevant dimensions, as it was the case in Fernández-Duque and Knight (2008). In contrast to that, in our study the type of stimuli and the type of task were kept constant across conflict types, suggesting that these might be the key conditions under which proportion congruent effects can indeed generalize across conflict types. To sum up, we propose that depending on the whether the two proportion congruent contexts are made more or less different from each other in terms of stimulus features, we may observe situations where proportion congruent effects are context specific and others where there is generalization.

More research is still needed to fully understand all necessary and sufficient conditions that make proportion congruent effects specific or general across different types of conflict, stimuli and tasks. However, what is most critical from the present study is that it shows for the first time, that proportion congruent effects can indeed generalize across conflict types. More importantly, under identical experimental conditions, a dissociation can be demonstrated between proportion congruent and conflict adaptation effects: There was generalization across conflict types for the proportion congruent manipulation but not for conflict adaptation. Taken together, the present results point to these two forms of cognitive control operating via separate mechanisms.

Finally, we point out that the present data fit perfectly well with the computational model proposed by De Pisapia and Braver (2006) of dual control mechanisms, one reactive and one proactive. More concretely, they have proposed that a single mechanism, reactive control, exerts cognitive control based on the transient activation of the PFC following the detection of conflict in the ACC over a short time-scale. A second mechanism, proactive control, is also proposed, consisting in the sustained active maintenance of task set information in a separate PFC module. This is driven by conflict detected in a separate ACC unit operating across a longer time-scale. Of course, more research is still needed from neuroimaging and electrophysiology, as well as from behavioral studies, to fully understand the different brain dynamics that could be responsible for these two modes of control. For now, our results point to a functional difference between the processes that resolve different types of conflict, which can be measured purely using behavioral data.

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