Target–flanker discriminability affects conflict size but not sustained suppression

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ARTICLE INFO

Article history:
Received 11 February 2010
Received in revised form 14 November 2010
Accepted 22 November 2010
Available online 24 December 2010

PsycINFO classification:
2340
2346

Keywords:
Cognitive control
Suppression
Selective attention

ABSTRACT

On successive trials, repetitions of irrelevant information often tend to reduce congruency effects as compared to alternations of irrelevant information. The preferred explanation for this congruency modulation is the sustained-suppression hypothesis, suggesting that suppression of the irrelevant information on a given trial perseveres into the subsequent trial. However, in contrast to the generality of this idea, this modulation is only stable when the irrelevant information contains spatial features, which coincided in the existing research with large conflict sizes and response conflicts. In two arrow flanker experiments, we investigated whether the congruency modulation depends on the size of the conflict, by manipulating the saliency of the target (Experiment 1) and the flankers (Experiment 2). Although these manipulations affected the size of the conflict caused by the flankers, neither experiment showed an influence of conflict size on the reduction of the congruency effect for repetitions as compared to alternation of the irrelevant flankers. We conclude that sustained-suppression is not a consequence of large conflicts, at least if sustained-suppression causes the congruency modulation.

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1. Introduction

A typical aspect of congruency tasks is that irrelevant information influences the speed and accuracy of the response to the relevant information. When the irrelevant information is repeated, its influence decreases and sometimes disappears altogether. This reduction of the congruency effect for repeated irrelevant information as compared to alternated irrelevant information has been explained by sustained-suppression, suggesting that the irrelevant information is suppressed, and that this suppression persists into the next trial. The present article aims at clarifying whether the reduction of the congruency effect depends on the amount of interference caused by the irrelevant information.

In congruency tasks, as for example the Simon (1990), flanker (Eriksen & Eriksen, 1974) or Stroop (1935; for an overview see MacLeod, 1991) task, irrelevant information interferes with relevant stimulus or response information. For example, in a typical arrow flanker task, participants have to respond to the direction of a centrally presented arrow that is flanked by other arrows. The flanker arrows can be identical to (i.e. congruent; e.g.: <<<<<<) or different (i.e. incongruent; e.g.: >>>>>>) from the central target arrow. Generally, responses are faster and error rates lower for congruent than for incongruent stimuli. One wide-spread class of models explaining congruency effects are the so-called dual-route models (e.g., de Jong, Liang, & Lauber, 1994; Eimer, Hommel, & Prinz, 1995; Kornblum, Stevens, Whipple, & Requin, 1999; Kornblum & Stevens, 2002; Ridderinkhof, van de Molen, & Bashore, 1995). For instance, the dimensional overlap model of Kornblum and Stevens (2002), a dual-stage dual-route model, suggests two sequential stages at which interference can occur, namely the stimulus identification stage followed by the response selection stage. In this model, overlapping stimulus dimensions, such as an irrelevant colour word and a relevant colour in the Stroop task, are suggested to influence the duration of the stimulus identification stage. Overlap between a response dimension and an irrelevant stimulus dimension, as for example the irrelevant stimulus location and the lateralized response dimension in the Simon task, is proposed to affect the length of the response selection stage, due to automatic translation of the irrelevant stimulus dimension into a response code through a direct route. In case of irrelevant stimulus–response overlap, the automatic response activation can conflict with the outcome of the controlled route, i.e. with the response code activated by the task-set that operates on the relevant stimulus information. The resolution of this response conflict is suggested to require time, and hence, to delay the response to the relevant stimulus information.

Although the dual-route model of Kornblum and Stevens (2002) can explain congruency effects, some authors added an inhibitory component to this dual-route architecture to explain the resolution of response conflicts. For instance, Ridderinkhof (2002a,b) formulated the activation–suppression hypothesis. According to this hypothesis,
response activation due to irrelevant stimulus information accumulates over time. Concurrently, the irrelevant information is suggested to become increasingly suppressed with time. Hence, if the processing of the target stimulus along the controlled route is fast, i.e. for fast responses, irrelevant response activation (and the conflict) will be weak, as well as the suppression, and the congruency effect will be small. With increasing response time, irrelevant response activation will increase, but also the suppression will become more effective. As a consequence, the activation–suppression hypothesis predicts an increase in congruency effects with increasing response times that eventually should level off, or even reverse. This is typically represented in delta plots, where congruency effects are plotted as a function of response times. This is also what is observed when analyzing reaction time distributions in Simon tasks (Ridderkhoff, 2002a,b; Ridderkhoff, van den Wildenberg, Wijnen, & Burle, 2004). Additionally, these authors found that the slopes of the delta plots are more negative (or less positive) when the amount of cognitive control is increased. Suppression is assumed to be stronger with increased interference control, resulting in a more decreasing (or less increasing) congruency effect for slower response times.

Besides distributional analyses, there are several other findings that are in accordance with the activation–suppression hypothesis. Eimer (1999) and Eimer and Schlaghecken (1998), who included the measurement of lateralized readiness potentials (LPRs) in their studies, presented masked arrow priming stimuli that were either congruent or incongruent with a subsequent target arrow. They varied the prime–target interval, and obtained a congruency effect if the prime–target interval was short, and an inverted congruency effect for longer prime–target intervals. Also the LPRs supported a suppression mechanism, as the arrow prime initially elicited activation contralateral to the arrow prime direction, followed by activation ipsilateral to the prime direction. Similar indications were obtained by Flowers (1980) and Machado, Wyatt, Devine, and Knight (2007). These authors found that presenting flankers in advance to the target in flanker or flanker-like tasks reduced the flanker effect, and even reversed it when the stimulus-onset asynchrony was sufficiently long.

Support for a suppression mechanism has also been obtained by investigating the expected after-effects of suppression. In a wide range of serial reaction time tasks, decreased congruency effects occur when the irrelevant information is kept constant during a whole block of trials as compared to when the irrelevant stimulus dimension varies at random (Melara & Algorn, 2003; Melara, Wang, VU, & Proctor, 2008; Morein-Zamir, Henik, & Spitzer-Davidson, 2002; Pansky & Algorn, 2002). Although attentional accounts, relating continuous repetitions of irrelevant information to the uninformative nature of that information, may provide an explanation for the latter findings (Melara & Algorn, 2003), they are also highly consistent with the notion of sustained-suppression (MacLeod, 1991). According to this hypothesis, suppression of the irrelevant word during the preceding trial lingers on into the subsequent trial, resulting in less interference for sequences of suppressed repeated as compared to unsuppressed alternated words.

Important for the present research, repetitions of irrelevant information can also diminish or even eliminate congruency effects when the irrelevant information varies at random in a block of trials. Notebaert, Soetens, and Melis (2001) observed this effect in a Simon task, in which a congruency effect emerges due to an irrelevant lateralized stimulus location interfering with a lateralized response to a non-spatial attribute (e.g. colour) of a stimulus. In this study, the Simon effect was absent for repetitions of the irrelevant stimulus location on successive trials as compared to alternations of the irrelevant stimulus location. From now on, we will refer to this kind of observations as the congruency modulation, not to be confused with the so-called conflict adaptation effect. The latter effect is the observation of smaller congruency effects when the immediately preceding trial is incongruent as compared to congruent and is often suggested to reflect a control mechanism that prepares the cognitive system in order to avoid or reduce future conflicts (e.g. Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004).

Based on MacLeod (1991) original idea, Notebaert and Soetens (2006) suggested that the suppression of the irrelevant information gradually decays after the response has been given to the relevant information. Consequently, with short RSIs, repeated irrelevant information on the next trial will still be suppressed, and hence, cause a smaller congruency effect as compared to unsuppressed alternated information. Furthermore, with RSIs that are sufficiently long, suppression has already decayed considerably, and repeated irrelevant information will again be able to interfere, thereby generating a sizeable congruency effect. The decaying function of the suppression must be rather steep, as the congruency modulation already disappears with an RSI of 200 ms (Zeischka, Deroost, Maetens, & Soetens, 2010). This idea is very compatible with the activation–suppression hypothesis of Ridderkhoff (2002a,b) as it only adds a decay function to the suppression that accumulates during a trial.

The sustained-suppression hypothesis, however, is put forward as a general hypothesis, applicable to all kinds of stimulus features. In contrast, the congruency modulation turned out not to be a general phenomenon, but proved to be limited to irrelevant information containing spatial properties. In the Simon task (Notebaert & Soetens, 2003; Notebaert et al., 2001), where stimulus location is the irrelevant information, as well as in flanker tasks when using arrow stimuli (Notebaert & Soetens, 2006), the congruency modulation is stable and pronounced. On the other hand, in manual versions of the Stroop task, the congruency modulation is small, if at all reliable (Notebaert & Soetens, 2006; Notebaert, Verbruggen, & Soetens, 2005). For proper comparison, Zeischka et al. (2010) contrasted the congruency modulation in identical flanker tasks with spatial and nonspatial stimuli. This study clearly indicated that the congruency modulation only occurs with spatial information: the congruency modulation was clearly present in flanker tasks with arrow stimuli (Zeischka et al., 2010, Exp. 1 and 4), and absent in flanker tasks with colour or letter stimuli (Zeischka et al., 2010, Exp. 2 and 3). If sustained-suppression causes the congruency modulation, then this process might be specific to the processing of spatial information. In the remainder of this paper this version of the sustained-suppression hypothesis will be called the spatial hypothesis.

However, the use of spatial information often results in larger congruency effects and presumably larger conflicts. This is very clear in the flanker experiments of Zeischka et al. (2010), where a much larger congruency effect was obtained with arrows than with colours or letters as stimuli. Hence, the congruency modulation might be specific not only to the spatial nature of the interfering information, but also to high-conflict situations. Interestingly, other authors already related suppression to the amount of irrelevant activation. In a priming paradigm, Schlaghecken and Eimer (2002) demonstrated that the negative compatibility effects between prime and target (see above) turned into positive compatibility effects if the perceptual strength of the prime was decreased. The concept of a suppression threshold was invoked in order to account for these results: only irrelevant activation that exceeds a certain threshold is suggested to receive suppression. Returning to the congruency modulation, larger conflicts, as compared to smaller conflicts, may evoke a larger amount of suppression of the irrelevant information in resolving the larger conflict. Consequently, given an identically short RSI, a larger congruency modulation is expected for an increased conflict situation: the larger amount of suppression should require more time to decay completely and, hence, more suppression should be left over at the presentation of the next stimulus. For sufficiently long RSIs, no difference in congruency modulation is expected for small and large conflict conditions, as the suppression would already have decayed upon the next stimulus presentation. We will refer to this hypothesis as the conflict size hypothesis.

The current article examines the validity of the conflict size hypothesis. To this end, we systematically manipulated conflict size in
two arrow flanker experiments to find out whether the congruency modulation, observed in short RSI conditions, depends on conflict size. Finding a positive relation between conflict size and the congruency modulation would significantly strengthen the idea that the modulation is a result of the amount of suppression during the preceding trial. Additionally, we analyzed the delta plots in order to verify the assumption that increasing conflict size in the current experiments indeed resulted in more suppression. If the conflict size hypothesis is correct, we expected larger congruency effects, requiring more suppression, to be associated with less positive delta slopes, i.e. with congruency effects that increase slower or decrease faster with slowing RTs. Hence, increased conflict sizes should be accompanied by lower delta slopes and by larger congruency modulations. Failing to find so would reveal a disconnection between conflict size, suppression and sustained suppression. This would at least be inconsistent with the conflict size hypothesis, and might suggest that sustained-suppression is specific for spatial information or that another process than sustained-suppression causes the congruency modulation.

2. Experiment 1

In Experiment 1, we manipulated conflict size by varying (relative) target saliency, i.e. the colour of the target stimulus. While the flanker arrows were always presented in white, the target arrow was presented either in white (difficult selection condition) or yellow (easy selection condition). The different selection conditions were presented in separate blocks. The colour difference between target and flankers in the easy selection condition is known to cause a pop-out effect of the target arrow (Treisman & Gelade, 1980), which may facilitate target selection. This manipulation has also been demonstrated to reduce flanker interference (Baylis & Driver, 1992). Due to increased suppression, the conflict size hypothesis predicts more negative (or less positive) delta slope and a larger congruency modulation in the difficult as compared to the easy selection condition. The experiments were run with a short RSI of 50 ms (RSI50) and a long RSI of 1000 ms (RSI1000). The RSI50 condition was the critical condition where an effect of conflict size on the congruency modulation was expected, while the RSI1000 condition was a control condition. The congruency modulation should be larger in the RSI50 than in the RSI1000 condition, as (nearly) all suppression should have decayed when presenting the next stimulus in the RSI1000 condition. In summary, the conflict size hypothesis expected a larger interaction between RSI, flanker sequence, and congruency for the difficult selection condition than for the easy selection condition, due to a larger congruency modulation in the RSI50 condition for the difficult than for the easy selection condition.

2.1. Method

2.1.1. Participants

24 first-year psychology students of the Vrije Universiteit Brussel participated in this experiment. Age averaged 19 years, and varied between 18 and 27 years. All participants had normal or corrected-to-normal vision, and seven were male.

2.1.2. Materials

The stimulus array was a row of nine left or right pointing arrows. From a viewing distance of 60 cm, this array was about one visual degree high and seven visual degrees wide. The central arrow was the target stimulus and the flankers all pointed into the same left or right direction, independently of the target arrow direction. The flankers could thus point in the same (i.e. on congruent trials) or opposite (i.e. on incongruent trials) direction of the target arrow. All arrows were coloured in white (RGB: 255; 255; 255) in the difficult selection condition, while the flankers were white and the target yellow (RGB: 255; 255; 0) in the easy selection condition. As a fixation point, we used a white plus sign. Left responses were given with the “-”-key and right responses with the “+”-key of a standard qwerty keyboard. The background of the screen was always black (RGB: 0; 0; 0). The E-Prime software (Schneider, Eschman, & Zuccolotto, 2002a;2002b) controlled the experiment.

2.1.3. Procedure and design

A trial started with the presentation of the fixation cross in the middle of the screen. Depending on the RSI, the fixation cross remained on screen for 50 or 1000 ms. After the RSI the target–flanker stimulus was presented, with the target arrow appearing at the fixation point. Participants had to react as fast and as accurate as possible to the direction pointed at by the central arrow within a time frame of 1500 ms. If the response was correct, the fixation cross replaced the stimulus immediately upon the response and remained on screen during the RSI. If the response was incorrect or no response was recorded, a feedback message “WRONG” or “TOO LATE” appeared in Dutch for 500 ms in the middle of the screen, followed by the fixation cross of the next trial.

RSI and selection difficulty were manipulated block-wise. The experiment consisted of four blocks, one for each selection difficulty by RSI combination. Four orders of the blocks were possible. The first two blocks were with easy target selection, and the last two blocks with the difficult target selection, or vice versa. For both selection difficulties, the first block was with an RSI of 50 ms, and the second with an RSI of 1000 ms, or vice versa. The order of the blocks was counterbalanced across participants. Each block contained 240 trials in which the target and flanker arrows were randomly chosen. Half of the trials were (in)congruent, and half of the trials were flanker repetitions (alternations) in relation to the previous trial. In every RSI block this resulted, on average, in 60 trials per congruency by flanker sequence combination. After each block, a text message informed participants about their mean reaction time (RT) and error percentage in that block. The message also encouraged them to commit less than 10% errors while having an average RT below 600 ms. The experiment started with a practice block of twenty randomly chosen trials with the selection difficulty and RSI of the first experimental block.

2.2. Results and discussion

All participants were included in the analyses, as they all met the criteria of having an error rate (ER) lower than 10%, and a mean RT lower than 600 ms. Mean ER was 3.4% (SD = 1.5%), and a positive correlation between median RTs and ERs over conditions (M = 0.35, SD = 0.24) indicated that there was no speed-accuracy trade-off. This was computed by correlating for every participant the median RTs and the error rate over all conditions. A t-test revealed that the mean correlation over participants was significantly different from zero, t(23) = 7.162, p < 0.001. Median RTs and ERs were both separately analyzed in a 2 (selection difficulty) × 2 (RSI) × 2 (flanker sequence) × 2 (congruency) repeated measures ANOVA. Additionally, a distributional analysis on the congruency effects of the RTs, as an index of suppression (Riddervik, 2002a,b), was accomplished by a 2 (selection difficulty) × 2 (RSI) × 4 (RT bin) repeated measures MANOVA. In this analysis, for reasons of brevity, we only report the effects involving the factor BIN.  

2.2.1. RT

The ANOVA on the median RTs revealed significant main effects of selection difficulty, F(1, 23) = 29.85, p < 0.001, MSE = 2455.90, RSI, F(1, 23) = 22.19, p < 0.001, MSE = 10399.44, flanker sequence, F(1, 23) = 88.73, p < 0.001, MSE = 543.18, and congruency, F(1, 23) = 265.52, p < 0.001, MSE = 1152.49. In general, responses were faster in the easy (M = 447.2 ms, SD = 46.1 ms) than in the difficult (M = 474.8 ms, SD = 54.4 ms) selection condition, faster in the RSI1000 condition (M = 436.5 ms, SD = 41.3 ms) than in the RSI50 condition
(M = 485.5 ms, SD = 66.1 ms), faster for flanker repetition trials (M = 449.8 ms, SD = 45.4 ms) than for flanker alternation trials (M = 472.2 ms, SD = 52.7 ms), and for congruent (M = 432.8 ms, SD = 44.3 ms) than for incongruent trials (M = 489.3 ms, SD = 54.4 ms), indicating a clear congruency effect.

Congruency interacted with RSI, F(1, 23) = 53.00, p < 0.001, MSE = 403.01, reflecting a larger congruency effect for the RSI1000 condition (M = 71.4 ms, SD = 17.0 ms) than the RSI50 condition (M = 41.5 ms, SD = 22.1 ms). Importantly, congruency also interacted significantly with selection difficulty, F(1, 23) = 24.71, p < 0.001, MSE = 457.70. The congruency effect was clearly larger in the difficult selection condition (M = 67.3 ms, SD = 24.6 ms) as compared to in the easy selection condition (M = 45.6 ms, SD = 14.1 ms), confirming that the intended manipulation of conflict size was successful. This also replicated the results of Baylis and Driver (1992). The three-way interaction between selection difficulty, RSI, and congruency, however, also turned out to be significant, F(1, 23) = 6.67, p < 0.017, MSE = 220.94. This interaction reflected a larger difference in the congruency effect between the easy and difficult selection conditions in the RSI50 than in the RSI1000 condition. Contrasts revealed that the interaction between selection difficulty and congruency was present in both the RSI50, F(1, 23) = 22.78, p < 0.001, MSE = 459.80, and the RSI1000 condition, F(1, 23) = 15.56, p < 0.004, MSE = 218.84.

To the heart of our research question is the presence of a significant interaction between flanker sequence and congruency, F(1, 23) = 73.09, p < 0.001, MSE = 291.44, as well as between RSI, flanker sequence, and congruency, F(1, 23) = 43.56, p < 0.001, MSE = 189.42. Flanker repetition trials were marked by a sizeably smaller congruency effect of 41.6 ms (SD = 15.2 ms) as compared to flanker alternation trials (M = 71.4 ms, SD = 22.2 ms), and this difference was larger for the RSI50 than for the RSI1000 condition. In terms of sustained-suppression, this would indicate that the suppression of the irrelevant information has already considerably decayed during an RSI of 1000 condition. Crucially, selection difficulty did not influence this pattern, as indicated by the absence of a significant four-way interaction between selection difficulty, RSI, flanker sequence, and congruency, F < 1 (see Fig. 1). Furthermore, planned contrasts illustrated that the RSI × flanker sequence × congruency interaction was significant for both the easy, F(1, 23) = 20.25, p < 0.001, MSE = 157.33, and the difficult selection condition, F(1, 23) = 24.41, p < 0.001, MSE = 212.53. Additionally, the congruency modulation was present in the RSI50 condition, F(1, 23) = 29.95, p < 0.001, MSE = 329.28, and in the RSI1000 condition, F(1, 23) = 5.03, p < 0.035, MSE = 75.53, of the easy selection condition. Similarly, also for the difficult selection condition, there was a congruency modulation in the RSI50 condition, F(1, 23) = 39.98, p < 0.001, MSE = 472.75, and in the RSI1000 condition, F(1, 23) = 8.97, p < 0.007, MSE = 141.50. Importantly, contrasts demonstrated that there was no difference in the congruency modulation between the easy and the difficult selection conditions in the RSI50 condition, F(1, 23) = 1.79, p < 0.195, MSE = 407.19, as well as in the RSI1000 condition, F < 1. The analysis of the RTs shows that, in this experiment, the congruency modulation is unaffected by the size of the congruency effect or of the conflict.

2.2.2. ER

The 2 (selection difficulty) × 2 (RSI) × 2 (congruency) ANOVA for the ERs revealed significant main effects of flanker sequence, F(1, 23) = 28.15, p < 0.001, MSE = 10.4, and congruency, F(1, 23) = 55.67, p < 0.001, MSE = 27.2, and a marginally significant effect of RSI, F(1, 23) = 4.19, p < 0.053, MSE = 21.5. Flanker alternation trials (M = 4.2%, SD = 2.0%) were more error prone than flanker repetition trials (M = 2.5%, SD = 1.4%), as well as incongruent (M = 5.4%, SD = 2.7%) in comparison to congruent (M = 1.4%, SD = 0.7%) trials. More errors tended to occur in the RSI1000 condition (M = 3.9%, SD = 2.4%) than in the RSI50 condition (M = 2.9%, SD = 1.2%). The only significant interactions were between selection difficulty and congruency, F(1, 23) = 12.99, p < 0.002, MSE = 4.3, RSI and congruency, F(1, 23) = 16.10, p < 0.001, MSE = 24.3, and flanker sequence and congruency, F(1, 23) = 26.95, p < 0.001, MSE = 7.2. As can be seen in Table 1, the congruency effect in the error rates was more pronounced for the difficult (M = 4.7%, SD = 3.1%) than for the easy (M = 3.2%, SD = 2.5%) selection condition, which additionally supports the effectiveness of the conflict size manipulation. The ER congruency effect was also larger in the RSI1000 condition (M = 6.0%, SD = 4.5%) than in the RSI50 condition (M = 1.9%, SD = 2.3%), and for flanker alternation trials (M = 5.4%, SD = 3.6%) as compared to flanker repetition trials (M = 2.5%, SD = 2.1%). The latter effect is consistent with the notion of sustained-suppression, although it is somewhat surprising that the congruency modulation in the ERs did not decrease with increasing RSI. The most important result from the ER analysis, however, is that the difference in congruency effect between flanker repetitions and alternations was not affected by the conflict size manipulation.

2.2.3. Distribution analysis

We assumed that larger conflicts, caused by stronger irrelevant activation, would result in larger amounts of suppression because more irrelevant activation may have to be suppressed. According to the activation-suppression hypothesis, differences in the amount of suppression should be reflected into different delta plots: the more suppression, the more the congruency effect should level off or decrease with increasing RT, relative to a condition with less suppression (Ridderinkhof, 2002a,b). If the activation-suppression hypothesis is correct, then the congruency effect should decrease

![](image)

**Fig. 1.** Mean median reaction times (RTs) of Experiment 1 in ms as a function of response-stimulus interval (RSI), flanker sequence and congruency. The left panel contains the data for the easy selection condition, and the right panel for the difficult selection condition. RSI50 = RSI of 50 ms, RSI1000 = RSI of 1000 ms, FREP = flanker repetition trials, FALT = flanker alternation trials, CG = congruent, and IG = incongruent.

<table>
<thead>
<tr>
<th>RSI of 50 ms</th>
<th>Easy target selection</th>
<th>Difficult target selection</th>
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<tbody>
<tr>
<td></td>
<td>Flanker repetitions</td>
<td>Flanker alternations</td>
</tr>
<tr>
<td>Congruent</td>
<td>2.2 (2.1)</td>
<td>2.1 (2.5)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>2.3 (2.5)</td>
<td>4.2 (4.0)</td>
</tr>
<tr>
<td>RSI of 1000 ms</td>
<td></td>
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</tr>
<tr>
<td>Congruent</td>
<td>0.9 (1.5)</td>
<td>1.5 (1.7)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>4.9 (1.7)</td>
<td>8.1 (6.6)</td>
</tr>
</tbody>
</table>

**Table 1** Mean error rates (and standard deviations) in percentage as a function of selection difficulty, response stimulus interval (RSI), flanker sequence, and congruency for Experiment 1.
more, or at least increase less with increasing RT, in the difficult than in the easy selection condition. Fig. 2 shows that this is clearly not happening. The 2 (selection difficulty)×2 (RSI)×4 (BIN) repeated measures MANOVA of the congruency effects revealed a significant two-way interaction between RSI and BIN, \( F(3, 21) = 6.36, p<0.004 \), and importantly between selection difficulty and BIN, \( F(3, 21) = 7.97, p<0.001 \). The congruency effect grew at a slower pace with increasing RT in the RSI1000 condition than in the RSI50 condition, and a much flatter delta slope was obtained for the easy than for the difficult selection condition. Also the interaction between selection difficulty, RSI, and BIN was significant, \( F(3, 21) = 11.03, p<0.001 \), reflecting that the interaction between selection difficulty and BIN was more pronounced in the RSI50 than in the RSI1000 condition. According to the activation-suppression hypothesis this distribution analysis would suggest that there was more suppression in the easy than in the difficult selection condition, and that this pattern was stronger in the RSI50 than in the RSI1000. The validity of this conclusion will be treated further in the General discussion. These conclusions are opposite to our initial assumptions about a relation between conflict size and suppression, but even then, these differences in suppression do not appear to be accompanied by a difference in congruency modulation.

In sum, despite marked differences in the congruency effect between the easy and difficult selection conditions, the current experiment did not find a relation between the size of the congruency effect and the size of the congruency modulation. If sustained-suppression causes the congruency modulation, then these results seem to suggest that conflict size does not influence the amount of sustained-suppression.

3. Experiment 2

The absence of a change in the congruency modulation may be caused by the fact that in both conditions the same arrow flankers were used. The influence of target selection difficulty on conflict size in Experiment 1 might rather reflect the clarity of the relevant stimulus instead of the amount of irrelevant activation that needs to be suppressed. Because the suppression is assumed to act on the irrelevant activation (Ridderinkhof, 2002a,b), and as the quantity of suppression might depend on the amount of irrelevant activation (Schlaghecken & Eimer, 2002), the level of irrelevant activation itself rather than conflict size per se might be essential. Therefore, we manipulated the saliency of the flanker arrows in Experiment 2, instead of the saliency of the target arrow. We kept the colour of the target arrow constant (i.e. white), and varied the brightness of the flanker arrows. In the difficult selection condition, both the target and flanker arrows were white, while in the easy selection condition the flankers were presented in gray. Besides creating a pop-out effect of the target, this also decreases the discriminability of the flanker arrows (A similar procedure to influence the magnitude of interference was also used by Schlaghecken & Eimer, 2002). This may further diminish the congruency effect. If there is a relationship between conflict size and the congruency modulation, then we expect to see a smaller delta slope and a larger congruency modulation for the difficult than for the easy selection condition.

3.1. Method

3.1.1. Participants

24 first-year psychology students of the Vrije Universiteit Brussel participated in this experiment. Age averaged 19 years, and varied between 18 and 20 years. All participants had normal or corrected-to-normal vision, and 5 were male.

3.1.2. Materials, procedure and design

Procedure and design were identical to Experiment 1, as well as the stimuli used in the difficult selection condition. The stimuli in the easy selection condition, on the other hand, consisted of a white target arrow, and gray flankers (RGB: 127; 127; 127), half as bright as the flankers in the difficult selection condition.

3.2. Results and discussion

All participants performed well with average ERs lower than 10% and RTs faster than 600 ms. There were no indications of a speed-accuracy trade-off, as the mean correlation between RTs and ERs was positive, \( r=0.29, \( t(23)=6.15, p<0.001 \). The same analyses as in the previous experiment were performed on median RTs and ERs and congruency effects.

3.2.1. RT

All main effects in the 2 (selection difficulty)×2 (RSI)×2 (flanker sequence)×2 (congruency) repeated measures ANOVA on the median RTs were significant. RTs were faster for the easy (\( M = 460.2 \) ms, \( SD = 44.3 \) ms) than for the difficult (\( M = 491.6 \) ms, \( SD = 52.6 \) ms) selection condition, \( F(1, 23) = 13.02, p<0.002, MSE = 7246.35 \), for the RSI1000 (\( M = 442.6 \) ms, \( SD = 38.6 \) ms) than for the RSI50 (\( M = 509.1 \) ms, \( SD = 55.7 \) ms) condition, \( F(1, 23) = 71.51, p<0.001, MSE = 5933.82 \), for flanker repetition trials (\( M = 465.0 \) ms, \( SD = 39.2 \) ms) compared to flanker alternation trials (\( M = 486.8 \) ms, \( SD = 49.3 \) ms), \( F(1, 23) = 47.35, p<0.001, MSE = 966.12 \), and for congruent (\( M = 450.5 \) ms, \( SD = 37.5 \) ms) compared to incongruent (\( M = 501.3 \) ms, \( SD = 51.7 \) ms) trials, \( F(1, 23) = 135.69, p<0.001, MSE = 1821.09 \).

As in Experiment 1, there was a significant interaction between RSI and congruency, \( F(1, 23) = 20.02, p<0.001, MSE = 694.75 \), revealing a larger congruency effect in the RSI1000 condition (\( M = 62.8 \) ms, \( SD = 21.7 \) ms) than in the RSI50 condition (\( M = 38.7 \) ms, \( SD = 28.5 \) ms). Crucially, our manipulation resulted again in the intended interaction between selection difficulty and congruency, \( F(1, 23) = 9.71, p<0.005, MSE = 1059.27 \), with the congruency effect being larger in the difficult selection condition (\( M = 61.1 \) ms, \( SD = 33.9 \) ms) than in the easy selection condition (\( M = 40.4 \) ms, \( SD = 17.0 \) ms).

Importantly, flanker sequence and congruency interacted significantly, \( F(1, 23) = 61.22, p<0.001, MSE = 287.32 \), showing a clear congruency modulation with the congruency effect being in general smaller for flanker alternation trials (\( M = 37.2 \) ms, \( SD = 17.7 \) ms) than for flanker repetition trials (\( M = 64.3 \) ms, \( SD = 27.2 \) ms). Contrasts showed that this was the case in both the RSI50 condition, \( F(1, 23) = 6.92, p<0.015, MSE = 1348.61 \), and the RSI1000 condition, \( F(1, 23) = 7.90, p<0.010, MSE = 276.87 \). This pattern was modulated by RSI, \( F(1, 23) = 20.57, p<0.001, MSE = 196.87 \), showing that the congruency modulation was much stronger in the RSI50 condition than in the RSI1000 condition. Finally, selection difficulty, RSI,
flanker sequence and congruency did not interact, $F=1$, indicating that the RSI x flanker sequence x congruency interaction was identical for the easy and difficult selection conditions. In Fig. 3, it can be seen that the results for the easy and difficult selection conditions are highly similar. As in Experiment 1, this again illustrates that the congruency modulation is not influenced by the size of the overall congruency effect. Furthermore, planned contrasts showed that the interaction between RSI, flanker sequence and congruency was present in both the easy, $F(1, 23) = 12.02$, $p<0.003$, $MSE = 123.11$, and the difficult selection conditions, $F(1, 23) = 8.56$, $p<0.008$, $MSE = 310.27$. Contrasts also revealed that the congruency modulation in the RS150 condition was similar for the easy and difficult selection conditions, $F=1$, as well as in the RS1000 condition, $F=1$. Finally, in the easy selection condition, the congruency modulation was present in the RS100, $F(1, 23) = 20.52$, $p<0.001$, $MSE = 567.27$, and the RS1000 condition, $F(1, 23) = 16.69$, $p<0.001$, $MSE = 73.35$, which also happened in the difficult selection condition, $F(1, 23) = 32.05$, $p<0.001$, $MSE = 243.72$, resp., $F(1, 23) = 12.41$, $p<0.002$, $MSE = 93.12$. In other words, the congruency modulation and its temporal aspects were identical in the easy and difficult selection conditions. In the logic of sustained-suppression, this suggests that sustained-suppression is independent of conflict size, and of the amount of suppression that may be related to conflict size.

3.2.2. ER
The $2 \times 2 \times 2$ (RSI) x FALT\textsuperscript{a} x congruency ANOVA on the ERs showed significant main effects of flanker sequence, $F(1, 23) = 28.77$, $p<0.001$, $MSE = 7.95$, and congruency, $F(1, 23) = 49.29$, $p<0.001$, $MSE = 20.1$. More errors were made on flanker repetition trials ($M=3.6\%$, $SD=1.8\%$) as compared to flanker alternation trials ($M=2.1\%$, $SD=1.3\%$), and on incongruent ($M=4.5\%$, $SD=2.4\%$) as compared to congruent trials ($M=1.2\%$, $SD=0.9\%$). There were significant interactions between RSI and congruency, $F(1, 23) = 24.53$, $p<0.001$, $MSE = 3.8$, and flanker sequence and congruency, $F(1, 23) = 6.26$, $p<0.009$, $MSE = 7.2$. No other effects were significant (all $p>0.05$). The congruency effect was larger in the RS1000 condition ($M=4.2\%$, $SD=2.6\%$) than in the RS150 condition ($M=2.2\%$, $SD=2.2\%$), and for flanker alternation trials ($M=4.0\%$, $SD=2.9\%$) as compared to flanker repetition trials ($M=2.4\%$, $SD=2.3\%$). Also in the ERs the pattern of Experiment 1 is replicated, with the congruency modulation being unaffected by the conflict size. The mean and standard deviation of the ERs can be consulted in Table 2.

3.2.3. Distribution analysis
The $2 \times 2 \times 4$ (RSI) x FALT\textsuperscript{a} x congruency ANOVA of the congruency effects only revealed a significant interaction between RSI and BIN, $F(3, 21) = 7.45$, $p<0.002$, reflecting a more positive delta slope in the RS150 than in the RS1000 condition (see Fig. 4). According to the activation–suppression hypothesis, this reflects more suppression in the RS1000 conditions than in the RS150 conditions, but alternatively, this may also point to more difficulties in suppressing the irrelevant flankers in the RS150 than in the RS1000 condition. In contrast to Experiment 1, the delta slopes were identical for the easy and difficult selection conditions, as indicated by the nonsignificant interaction between selection difficulty and congruency, $F=1$. Also here, it remains an open question whether these identical delta slopes reflect an equal amount of suppression, or whether a larger amount of suppression of the stronger interfering irrelevant information in the difficult selection condition is required to obtain a delta slope similar to the one in the easy selection condition. Finally, the interaction between selection difficulty, RSI, and BIN was nonsignificant, $F=1$. Thus, manipulating the perceptual strength of the flankers resulted only in a main effect on the congruency effect, without affecting the slope of the delta plots. The manipulations of Experiments 1 and 2 apparently have differentially influenced the delta plots, as varying target saliency in Experiment 1 clearly modulated the delta slopes. This indicates that both experiments did not affect (only) a common factor, such as relative target–flanker saliency. Although speculative, the colour-based pop-out of the target in Experiment 1 might have reduced stimulus conflict by allowing feature-based target selection or flanker suppression, which might be much less the case in Experiment 2. The difference in delta plots between both experiments is very pronounced with an RSI of 50 ms in the easy selection conditions, where the delta slope is much more positive in Experiment 2 than in Experiment 1. The congruency modulation in both these conditions was however identical, $F=1$. Within the logic of the activation–suppression hypothesis this would imply a disconnection between the congruency modulation and the amount of suppression: Under RS150 conditions, there is less suppression in Experiment 1 as compared to Experiment 2, but this is not accompanied by a decreased congruency modulation in Experiment 1 compared to in Experiment 2.

4. General discussion
In the present research we investigated whether reduced congruency effects for repeated irrelevant information as compared to alternated irrelevant information are related to the amount of conflict during the preceding trial, which may determine the strength of suppression in that specific trial. The theoretical goal of the investigation was to discriminate between two possible adaptations of the original sustained-suppression hypothesis (MacLeod, 1991; Flanker alternations):

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|}
\hline
\textbf{RSI of 50 ms} & \textbf{Flanker repetitions} & \textbf{Flanker alternations} & \textbf{Flanker repetitions} & \textbf{Flanker alternations} \\
\hline
Congruent & 1.3 (1.8) & 1.9 (1.9) & 1.1 (2.1) & 2.5 (2.7) \\
Incongruent & 2.7 (2.8) & 5.0 (4.3) & 2.8 (3.2) & 5.2 (3.6) \\
\hline
\end{tabular}
\caption{Mean error rates (and standard deviations) in percentage as a function of selection difficulty, response stimulus interval (RSI), flanker sequence, and congruency for Experiment 2.}
\end{table}
Notebaert & Soetens, 2006) that may account for the apparent limitation of the congruency modulation to spatial information (see e.g. Zeischka et al., 2010). First, the process underlying sustained-suppression may be specific to the processing of spatial information, instead of being a general process applicable to all kinds of stimuli. Second, sustained-suppression may depend on conflict size, as measured by the size of congruency effects.

The current research directly addressed the validity of the latter hypothesis, by manipulating the size of the congruency effect in two experiments. This was achieved by varying the target selection difficulty in comparable flanker tasks. Experiment 1 contrasted the congruency modulation in situations with and without pop-out of the target stimulus by presenting the target stimulus in a colour identical to or different from the flanker stimuli. The congruency effect was reduced when there was a pop-out of the target. However, despite the successful manipulation of conflict size, the congruency modulation did not increase for a large conflict situation (without target pop-out) compared to a small conflict situation (with target pop-out). Experiment 2 manipulated target selection difficulty by decreasing the brightness of the flanker stimuli. The results of the second experiment were very similar to those of Experiment 1: The congruency modulation was identical in size for the easy and the difficult selection conditions, despite a significantly smaller congruency effect in the easy selection condition.

The data of these experiments are difficult to reconcile with the predictions of the conflict size version of the sustained-suppression hypothesis. These were that enhanced conflicts would lead to higher levels of suppression of the irrelevant information. With short RSiS, suppression is assumed to linger on into the subsequent trial, and into a stronger degree after a large than after a small conflict. Consequently, the residual suppression of repeated irrelevant information would be stronger after a large as compared to after a small conflict, in contrast to unsuppressed alternated irrelevant information. Hence, increased conflict sizes should be associated with increased congruency modulations. This was not confirmed in the current series of studies.

The assumption that increased conflicts would require more suppression to overcome the irrelevant activation and resolve the conflict was based on the experiments of Schlaghecken and Eimer (2002), who related the amount of irrelevant activation to the quantity of suppression. Also, if one adheres to the idea that suppression is a fundamental process in interference control, one must also assume that in order to respond correctly to incongruent trials, the irrelevant activation must have been suppressed sufficiently, and that a larger amount of suppression is required to overcome stronger interfering irrelevant activation. In order to have some measure to verify this assumption we used distributional analyses and interpreted them following the logic of the activation–suppression hypothesis (Ridderinkhof, 2002a,b). According to this hypothesis, during a trial, increased irrelevant response activation is becoming increasingly suppressed, resulting in delta slopes that should either increase followed by a decrease, or level off. More suppression in one condition relative to the other should be expressed by a more negative, or a less positive, delta slope for the condition with the most suppression relative to the other. We did not obtain consistent patterns with regard to this assumption. While the high-conflict condition in Experiment 1 was marked by a clearly more positive delta slope than the low conflict condition, the delta plots of easy and difficult selection conditions seemed to be rather similar in Experiment 2.

However, an important question is whether these delta plots are appropriate to investigate the amount of suppression in a specific condition. We think that one should be very cautious when interpreting distributional analysis in terms of suppression. In particular, we are concerned that the activation–suppression hypothesis does not adequately take into account that a distribution is composed of at least two processes which may both vary. Although the activation–suppression hypothesis assumes that the function of suppression can differ across subjects and conditions on several aspects such as strength, onset and build-up rate (Ridderinkhof et al., 2004), a necessary assumption for the activation–suppression hypothesis, in order to be able to draw conclusions about suppression, is that the rate of increase of irrelevant activation across the subjects and/or conditions in comparison must be constant. This assumption might be incorrect and if suppression is involved in conflict resolution, delta plots may rather reflect the relative contribution of both the rate of increase in irrelevant activation and the rate of increase in suppression. Consider for instance the delta plots of Experiment 1. While the nearly flat delta slopes for the easy as compared to the difficult selection condition might reflect more suppression in the easy than in the difficult condition, it may equally well reflect a smaller increase in irrelevant activation due to an easy pop-out based target selection, combined with an identical or even a smaller amount of suppression as compared to the difficult selection condition.

More positive delta slopes may reflect a relative difficulty in overcoming interference on incongruent trials, probably causing wider RT distributions on incongruent than on congruent trials. In our opinion, the very positive delta slope in the difficult selection condition of Experiment 1 may point to a failure to suppress strongly increasing irrelevant activation sufficiently in a fast and efficient way, relative to the easy selection condition. Or in other words, the ratio between the increase rate of irrelevant activation and the increase rate of suppression may have been higher in the difficult than in the easy selection of Experiment 1. Therefore, distributional analyses are inappropriate to determine the amount of suppression. Anyway, if the obtained delta plots would truly reflect differences in suppression, they are not associated with differences in the size of the congruency modulation. Thus, even if the logic of the activation–suppression hypothesis would be valid, the congruency modulation would not be related to the amount of suppression.

Although we did not find a relation between conflict size and the congruency modulation, the current data do not need to be incompatible with the notion of sustained-suppression per se. The current experiments are not in line with the prediction of the conflict-size version of the sustained-suppression account, but they are with at least two other possible adaptations to the sustained-suppression hypothesis. First, Schlaghecken and Eimer (2002) suggested a discontinuous relation between the amount of irrelevant activation and suppression. They suggested a threshold that needs to be surpassed by the irrelevant activation in order to trigger suppression. In the current study, decreasing conflict size resulted in congruency effects that were still larger than those found in flanker tasks with non-spatial stimuli. Hence, it may be possible that irrelevant activation in the present experiments crossed the threshold in both the high and low conflict conditions, causing similar amounts of
suppression in both conditions. An experiment increasing conflict size in non-spatial flanker tasks may resolve this issue.

Second, a response-conflict adaptation of the sustained-suppression hypothesis might be formulated. In the existing research, the presence of spatial irrelevant features with the congruency modulation also coincided with the presence of irrelevant stimulus-response overlap. According to Ridderinkhof (2002a,b), irrelevant response activation, which only occurs with stimulus-response overlap, would trigger suppression. If the congruency modulation is an after-effect of the suppression process proposed by Ridderinkhof, then the congruency modulation should obviously arise only in tasks involving irrelevant stimulus-response overlap. Additionally, stimulus-response overlap may also be important because of the timing aspects of suppression. Following the dual-route model of Kornblum and Stevens (2002), response conflicts due to stimulus-response overlap are resolved later in time than stimulus conflicts, which are elicited by irrelevant stimulus-stimulus overlap. As the decay of suppression must be rather steep (Zeischka et al., 2010), the suppression of irrelevant stimulus activation may already have decayed on the next stimulus presentation, as opposed to the suppression of irrelevant response activation. Note that there are indications of suppression in perceptual tasks, e.g. negative priming (Neill, 1977), even though the model of Kornblum and Stevens (2002) does not include a suppression mechanism to resolve stimulus conflicts.

Third, as mentioned in the Introduction, sustained-suppression might be specific for irrelevant spatial information. This may explain the insensitivity of the congruency modulation to conflict size. The mere presence of spatial properties of the irrelevant information would be sufficient to elicit its suppression. The amount of suppression may then be independent of conflict size, causing similar congruency modulation in low and high conflict situations. The processing of spatial and nonspatial information may, at least for a part, be subserved by different neural substrates (e.g. Mishkin, Ungerleider, & Macko, 1983), which also raises the possibility of functional differences in the processing and in interference control in the spatial and nonspatial domain.

Alternatively, hypotheses not related to suppression might account for the congruency modulation. Because stable congruency modulations seem to be restricted to spatial information, the spatial attention-shift hypothesis (Notebaert et al., 2001; Stoffer & Yakin, 1994; Umiltà & Nicoletti, 1992) may explain the congruency modulation in general. This hypothesis was in origin put forward as an explanation for the Simon effect, where an irrelevant stimulus location interferes with a lateralized response required to a nonspatial stimulus attribute. According to this hypothesis, shifts of attention into a particular direction create a spatial code that serves as the input of the automatic route of the dimensional overlap model (Kornblum & Stevens, 2002), which in turn results in automatic response activation corresponding to the direction of the shift of attention. As a consequence, a congruency effect emerges because these irrelevant response activations interfere with the processing of the relevant response information. This hypothesis can explain the congruency modulation in serial Simon tasks (Notebaert et al., 2001). With a short RSI of 50 ms, no shifts of attention occur for repetitions of the stimulus location because the RSI is too short to shift attention back towards a central fixation point. This contrasts with location alternation trials, where a shift of attention is always required, and hence, a Simon effect is observed. Although attention-shifts may be useful in the Simon task because they bring the relevant information into the focus of attention, they are not in flanker tasks, as this would bring irrelevant flankers into attention. Nonetheless, the attention-shift hypothesis may also apply to arrow flanker tasks, because they may exogenously bias attention into the direction they are pointing at, thereby generating an interfering spatial code as in the Simon task. Repeated arrow flankers within a short time frame might not activate that spatial code again, as attention would still be biased into the repeated arrow flanker direction. In other words, there could be a Simon-like effect in arrow flanker tasks on top of the flanker effect common to all types of flanker tasks. However, Zeischka, Deroost, Henderickx, and Soetens (2010) demonstrated that attention is not biased into the direction of the flanker arrows. Also, the insensitivity of the congruency modulation to flanker saliency (see Experiment 2) contradicts the expectations of the attention-shift hypothesis. Decreasing the saliency of exogenous cues is associated with smaller cueing effects (Fuller, Park, & Carrasco, 2009). Because the arrow flankers in short RSI conditions are supposed to cause attention-shifts only for flanker alternation trials, decreased saliency of the flanks should have resulted in a smaller congruency effect for flanker alternation trials, and hence, in a reduced congruency modulation. Apparently, this was not the case.

Another attention-based account for the congruency modulation can be found in the tectonic theory of attention (Melara & Algom, 2003). Reduced congruency effects are also obtained when the irrelevant information is kept constant during a block of trials as compared to when it randomly varies. This is a very stable finding, observed in many different congruency tasks with longer RSIs (Melara & Algom, 2003; Melara et al., 2008; Morein-Zamir et al., 2002; Pansky & Algom, 2002). In their tectonic theory, Melara and Algom (2003) suggested that the information value of a perceptual dimension is a crucial factor in the allocation of attention. Informative dimensions would receive more attention than non-informative dimensions. The variability of a dimension would be a key determinant of its informativeness. Hence, repeating irrelevant information renders that dimension uninformative, resulting in decreased attention for the repeated dimension and reduced interference by it. Perhaps the congruency modulation under short RSI conditions in tasks with randomized presentation of irrelevant information might be a precursor of the process reducing the congruency effect in block-wise repetitions. However, such an account suffers from similar problems as the sustained-suppression hypothesis. In contrast to the congruency modulation, which seems to be specific for irrelevant spatial information, the small congruency effect for constant irrelevant dimensions is much more general across tasks and stimuli.

Finally, the results of Burt (2002), who used a prime–target version of the non-colour-word Stroop task, are noteworthy. In this task, participants had to name the colour in which an irrelevant non-colour-word appeared (e.g. “KING” in blue), which was preceded by a prime word that was either identical or unrelated to the target word. In this paradigm the prime word is not involved in a conflict and therefore probably receives no suppression. Nevertheless, Burt observed that responses to the colour of the target word were faster when the prime word was identical to the target word compared to an unrelated word. This was interpreted as a facilitation of the processing of the irrelevant target word by presenting the identical word in advance, resulting in a decreased overlap in time or decreased magnitude of concurrent processing of the colour and the interfering target word. In the same way, this may explain why responses in congruency tasks are generally faster when the irrelevant information is repeated as compared to alternated. Additionally, this may account for the congruency modulation: Repeating irrelevant information may enhance or speed up the processing of the irrelevant information significantly, and decrease the interference caused by the irrelevant information. Such a process would not take place on trials with an alternation of the irrelevant information, hence, causing a larger congruency effect for repeated than for alternated irrelevant information. However, Burt (2002) also showed that this facilitation effect turned into an interference effect when the task promoted phonological activation of the prime word. This would result in an enhanced phonological processing of the target word when it was identical to the prime as compared to unrelated, which, for repeated words, may cause a larger conflict with the (phonological code of the) vocal response that had to be given to the colour. Since both the
relevant and irrelevant information in a flanker task are on each trial processed according to the task instructions, thereby causing a conflict, it seems as if this explanation would predict larger congruency effects for repeated than for alternated flankers, i.e. an inverted congruency modulation.

In conclusion, our results indicate that the congruency modulation seems to be independent of conflict size. Therefore, the occurrence of a stable congruency modulation when using spatial information is probably not an after-effect of relatively large amounts of suppression caused in situations with large conflicts. This is not to say that suppression may not be a central mechanism in conflict resolution or that the sustained-suppression hypothesis cannot account for the congruency modulation, but that other adaptations of the sustained-suppression hypothesis have to be considered for an adequate explanation of the observed pattern of results. More precise, sustained-suppression might be specific to the processing of spatial information, or sustained-suppression could follow after a response conflict, but not after a stimulus conflict.

Acknowledgements

This research was supported by a research grant from the National Fund of Scientific Research, Flanders, Belgium (FWO-VL G.0016.05N) and the Research Council of the Vrije Universiteit Brussel (OZR1905).

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