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Dynamics of facilitation and interference in cue-priming and Simon tasks

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In examining the selective suppression of responses activated by task-irrelevant stimulus attributes, such as in spatial conflict tasks, two different approaches have pointed to similar conclusions. In one approach (involving cue-priming procedures), variations of the stimulus–onset asynchrony (SOA) between task-irrelevant cues and subsequent target stimuli disclosed that the cues elicit activation of the congruent response, but this activation is subsequently suppressed. In another approach, a series of studies with the Simon task led to the formulation of the activation-suppression hypothesis. Analysis of RT distributions (in particular delta plots) disclosed that the task-irrelevant stimulus location elicits activation of the spatially corresponding response, but this activation is subsequently suppressed. The strength or efficiency of selective response suppression is expressed in the slope of the delta plot. In the present study, we combined these two approaches and found that the effects of SOA manipulation and the results of the distributional analysis converged and were positively correlated, suggesting that they involve a common mechanism of response activation followed by the selective suppression of that activation.

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In choice reaction time (RT) tasks, RT is shorter and error rate lower when the position of the signal corresponds to the position of the required response, even if the position of the stimulus is completely irrelevant for the task. For example, when subjects have to issue a right-hand response to a green signal (and a left-hand response to a red signal), RT is generally shorter on congruent trials with a green signal appearing on the right of fixation than on incongruent trials with a green signal appearing on the left. Although subjects are instructed to respond as a function of the stimulus colour (relevant stimulus dimension), the entirely irrelevant position of the signal affects response speed. The RT difference between congruent and incongruent responses is often termed the Simon effect (Hedge & Marsh, 1975; see Simon, 1990, for a review). Over the years, several explanations have been proposed to account for the Simon effect, in terms of attention shift (Nicoletti & Umiltà, 1994), spatial coding (Craft & Simon, 1970), and stimulus–response binding (Hommel, 1998), to name a few (see Lu & Proctor, 1995, for an overview). Although those various accounts differ in several respects, there is a general agreement that the irrelevant stimulus dimension is processed (more or less) automatically, activating a code corresponding to its position, although the nature of this code (perceptual, or motor, or somewhere in between) is still a matter of debate (Lu & Proctor, 1995). Whatever the locus of the interference, if the codes activated by the irrelevant and the relevant stimulus dimensions correspond, the response will be fast (and error rate low), whereas if they do not, the RT will be lengthened (and error rate increased). Those ideas have been formalised in so-called dual-route models (de Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Ridderinkhof, van der Molen, & Bashore, 1995).

Simon, Acosta, Mewaldt, and Speidel (1976) showed that the Simon effect varies with time by introducing a delay between the presentation of the stimulus and the response of the subjects. They observed a decrease of the Simon effect as the time between the stimulus and the response increased. Likewise, Hommel (1993) observed a decrease of the Simon effect with time by manipulating several factors affecting the speed of processing of the irrelevant dimension such as the eccentricity of the signal, signal quality, and signal formation time. Hommel interpreted this decrease as reflecting a ‘‘spontaneous decay’’. While the studies quoted above used mean RT as their main dependent variable, de Jong et al. (1994) analysed the distribution of RTs (see also Hommel, 1996). They observed that the difference between the congruent and incongruent RT distributions obtained from a Simon task was large in the early part (containing fast RTs) but that the difference diminished for long RTs. In other words, when the RT is short, the location of the stimulus has a clear effect on performance, but as RT lengthens, the impact of the location on performance diminishes. This reduction in Simon interference is best visualised by the ‘‘delta-plot’’ technique (de Jong et al., 1994; Ridderinkhof, 2002a). Delta plots allow a convenient way to summarise the differences in distribution shapes. They are derived from the quantile–quantile plots, and represent the difference between congruent and incongruent conditions as a function of increasing RT (see Figure 1 for an example, and general method section for more details). The decrease in the Simon effect with increasing RT shows up in negative-going slopes of the delta plots (see Figure 1 for an example). Capitalising on the decrease in the Simon effect with increasing RTs, Ridderinkhof (2002a) extended the dual-route model and proposed that such a reduction of the stimulus-position effect over time is not a passive process, but that the activation induced by the irrelevant attribute is subsequently suppressed by an active inhibitory mechanism.[1] Such a suppression, however, takes time to build up. Therefore, fast-enough responses will escape this suppression, inducing a full-blown Simon effect, whereas slow responses will benefit from the inhibitory mechanism. On incongruent trials on which the correct response hand does not coincide with the location of the signal, the suppression acts upon the incorrect location-based response, thus facilitating the correct response. In contrast, slow responses to congruent trials will be relatively disfacilitated, because of the suppression of location-based activation of the correct response. In agreement with this *activation-suppression* hypothesis, varying the strength of suppression resulted in corresponding changes in the delta plot (Ridderinkhof, 2002b).

At this point, it should be noted that the activation-suppression model does not aim to provide a new explanation for the occurrence of the Simon effect. As a matter of fact, it shares with various models of the Simon effect the notion that the position of the stimulus activates the ipsilateral response code. It is compatible with, but largely orthogonal to most models that assume parallel processing of the two dimensions. The specific goal of the activation-suppression model is to account for the dynamics of the effects of direct activation of the response code (rather than a location in space) and of the subsequent suppression of that activation.

Capitalising on the notion of suppression, Burle, Possamaï, Vidal, Bonnet, and Hasbroucq (2002) reasoned that the more the incorrect response is activated, the stronger the suppression necessary to overcome that activation, and hence the steeper the delta-plot slopes. Based on recordings of electromyographic (EMG) activity of the muscles involved in the responses on the Simon task,

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[1] The concept of inhibition is poorly defined in the experimental psychology literature. We have attempted to define it more clearly elsewhere using physiological investigation of inhibitory mechanisms (Burle, Vidal, Tandonnet, & Hasbroucq, 2004). Here we shall use the term ‘‘inhibition’’ to refer to physiological phenomena, and suppression to refer to a functional level. The reason is that, although we do believe the inhibitory mechanisms discussed elsewhere (e.g., Aron, Robbins, & Poldrack, 2004; Band & van Boxtel, 1999; Burle et al., 2004) are at play in the phenomena reported in the present study, it is not currently established. Further research is needed to evaluate the kind of physiological inhibition mechanisms involved, if any, in the suppression evidenced at the behavioural level.

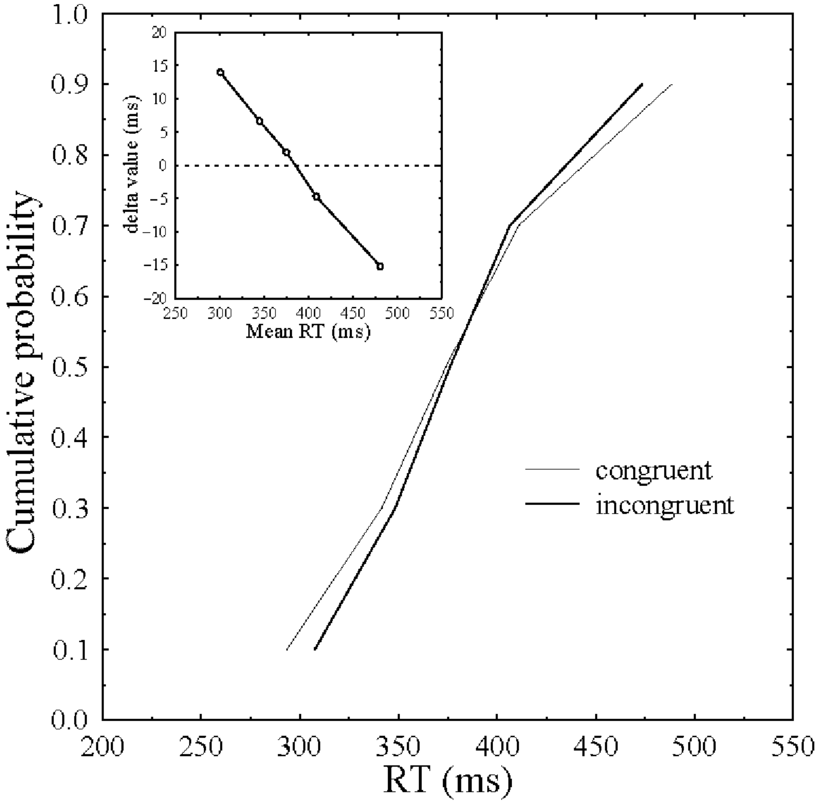

Figure 1. Cumulative density functions of RTs to congruent (thin line) and incongruent trials (thick line) and the corresponding delta plot (inserted panel). The cumulative density function represents the probability that the response was already given as a function of time post stimulus; it varies therefore between 0 and 1. The delta values represent the mean congruency effect (RT incongruent–RT congruent) calculated per quantile of the RT distributions. Delta slopes were computed by fitting a linear regression to the values across bins. Note that information on response dynamics is lost when reporting only the mean congruency effect computed over whole distributions, which is close to zero here. Data shown are from Experiment 1, SOA 150, averaged across 16 subjects.

Burle et al. separated trials showing subthreshold EMG activation of the incorrect response (partial errors) from trials without incorrect EMG. The prediction was confirmed: The delta plots were much more negative for partial errors than for other correct trials. In fact, this effect was so strong that the congruency effect for partial errors reversed for the longest RTs (i.e., congruent responses were slower than incongruent ones), indicating a negative congruency effect for the long RTs. This pattern showing an initial facilitation followed by a subsequent disfacilitation bears obvious resemblance with the data obtained in a different experimental context: the cue-priming procedures.

CUE-PRIMING PROCEDURES: ACTIVATION FOLLOWED BY INHIBITION

In cue-priming procedures, subjects are presented with two consecutive signals. The first signal (the ‘‘cue’’) is task irrelevant in the sense that it does not convey any information about the forthcoming target. The second signal (the ‘‘target’’) requires a discriminative response. Examples of cue-priming procedures are the ‘‘inhibition of return’’ (IOR) paradigm (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985; for a review, see Klein, 2000) and ‘‘masked-priming’’ tasks (Eimer & Schlaghecken, 1998). These tasks have several aspects in common. First, unlike purely valid cueing procedures (Rosenbaum, 1980), the cue provides no information about the forthcoming target. Second, subjects give a left or right response based on the target, but the task-irrelevant cues are sufficiently similar to targets to capture the attentional or response systems. Therefore, two types of trials can be defined. If the cue and the target convey the same information, the trial is congruent, whereas if the cue and the target are associated with different responses, the trial is incongruent. Third, the time between the presentation of the cue and the onset of the target (the stimulus–onset asynchrony, or SOA) is varied. In addition to these similarities, the IOR and the masked-priming tasks have one major difference. In the masked priming paradigm, the prime (or the cue) is not (at least not fully) accessible to awareness, whereas in the IOR, the cue is perfectly visible. We will elaborate on the possible implications of this distinction in the discussion section. A typical finding in these two types of priming tasks is a positive congruency effect, with shorter reaction time (RT) on congruent trials than on incongruent trials, but only for short SOAs. The reversed pattern is observed for longer SOAs, which commonly yield negative congruency effects, that is, responses to incongruent trials being faster than responses to congruent trials.

In the masked priming context, these results led Eimer and colleagues (e.g., Eimer, 1999; Eimer & Schlaghecken, 2002, 2003) to propose the activation-followed-by-inhibition hypothesis. In their view, the cue first transiently activates the associated response. For short SOAs, this leads to a direct positive congruency effect, characterised by slower RTs to the target on incongruent trials compared to congruent trials. However, as time passes, this activation is selectively suppressed, as becomes evident with longer SOAs. Consequently, if cue and target are separated by a longer delay, the response associated with the cue will be disfacilitated. As a result, a response to a target that is preceded by a congruent cue will be slowed because the suppression of the response previously activated by the cue must first be overcome. However, a response to a target preceded by an incongruent cue will be facilitated due to the suppression of its competitor. Similar explanations have been proposed to account for the IOR (Klein, 2000; Taylor & Klein, 2002). Therefore, one could expect a reversal of the congruency effect as the time between the cue and the target increases.

COMMON DYNAMICS OF INHIBITION ACROSS PARADIGMS?

Although the apparent similarities in the results across the cue-priming paradigm and the Simon-conflict paradigm have yielded similar interpretative frameworks (the facilitation-followed-by-inhibition account and the activation-suppression hypothesis), the question whether similar processes are involved awaits direct investigation. If the two phenomena described above are related, one may predict that the negative congruency effect observed in cue-priming procedures resemble a potent variety of the suppression revealed in the Simon task. Should this indeed be the case, then one may predict that positive congruency effects are due to a weak suppression, revealed in steep positive-going delta plots, whereas negative congruency effects are due to a strong suppression, reflected in less positive- or even negative-going delta plots. In other words, one may predict a positive correlation between the magnitude of the congruency effect and the slope of the delta plot. Experiment 2 of Eimer (1999) provides some suggestive evidence in favour of such a relation, associating a negative compatibility effect with negative-going delta plots (as inferred from the RT distribution graphs presented there).

In order to test the commonalities of the processes more specifically, one needs to design an experiment in which the two aspects outlined above can be evaluated in combination. To do so, one needs to dissociate in time the relevant and the irrelevant dimension of the presented signal in a Simon task. Several previous studies have done so by introducing an SOA between the relevant and the irrelevant dimension (Hommel, 1996; Ivanoff, 2003; Simon et al., 1976; Zimba & Brito, 1995) and have provided important information about the dynamics of Simon effect. However, those designs are not optimally suited to test the hypothesis presented above, as will be elaborated below.

The informative function of a stimulus refers to the fact that the stimulus provides the information about *which* response to give, whereas the imperative function refers to the fact that the stimulus indicates *when* to give the response (Gottsdanker & Shragg, 1985). In regular RT tasks, the two aspects of the stimulus are presented together in a single stimulation. With this distinction in mind, one can say that, in the Simon task, the stimulation conveys three dimensions: the relevant, the irrelevant, and the imperative one. In a regular Simon task, the three dimensions are presented at the same time. However, in order to estimate the dynamics of the incorrect response activation, as probed by the RT to the imperative stimulus, the following conditions must be met: (1) The irrelevant dimension must be separated in time from the imperative signal, and

(2) the relevant dimension and the imperative signal must be presented simultaneously. In this case, the RT to the relevant dimension will be directly affected by the level of activation (and/or suppression) of the response code induced by the irrelevant dimension. Note that these requirements were not met in the experiments quoted above, mainly because they were pursuing other goals. In Simon et al. (1976), the irrelevant and the relevant dimensions were presented simultaneously, followed by the imperative stimulus (subjects had to wait for a tone to trigger their response). In Zimba and Brito (1995), the position (the irrelevant dimension) was precued (with 80% validity), thus presented before the imperative stimulus. However, the irrelevant dimension was repeated with the relevant dimension and the imperative stimulus. Hence, even if the cue was suppressed, the irrelevant dimension presented at imperative stimulus time might well have triggered a new activation of the ipsilateral response code. Finally, in the studies reported by Hommel (1995, 1996) and Ivanoff (2003), the relevant dimension was presented before the irrelevant one, which served as imperative stimulus. If the irrelevant dimension was suppressed, it should have been the same whatever the SOA, and hence, their manipulation of SOA cannot reveal the dynamics of the suppression.[2]

For the present purposes, we therefore designed a protocol in which the above-described constraints are met, resorting to a version of the Simon task that differs slightly from the regular one. In an early study, Simon and Craft (1970) asked their subjects to move their right index finger from a central position to a button lighting up either on the right or on the left. Importantly, although entirely irrelevant for the task, an auditory signal was presented on some trials, either to the right or to the left ear. It could thus be presented on the same side as the correct response, or on the side of the incorrect response. Responses to the left light were faster when the tone was presented to the left ear than to the right ear, and responses to the right light were faster when the tone was presented to the right ear than to the left. Notebaert and Soetens (2003) recently replicated this accessory version of the Simon effect. Interestingly, in this version of the task, the relevant and irrelevant stimulus attributes are dissociated, and hence can be manipulated separately, both in space and in time. Furthermore, the relevant dimension and the imperative stimulus are presented simultaneously, whereas the irrelevant dimension can be varied independently in time from the relevant dimension and the imperative signal. In order to design an accessory Simon task more similar to the cue-priming tasks that induce negative congruency effects, we used an irrelevant lateralised visual cue that could appear at several intervals before (negative SOAs), at the same time, or after (positive

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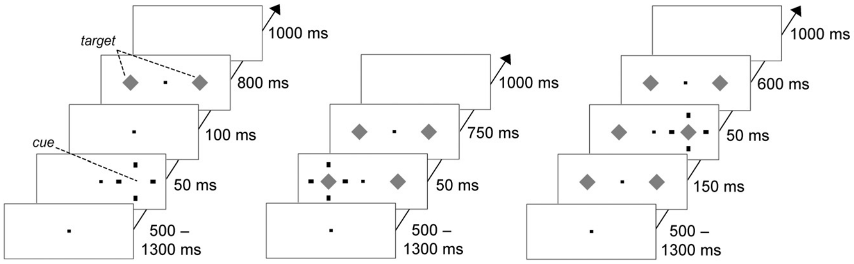
[2] Note that the logic behind the studies reported by Hommel and by Ivanoff is different from that of the present study. They were mainly interested in the interaction between the effect of the irrelevant dimension and the degree of preparedness of the (correct) response activated by the relevant dimension.



Negative SOA
cue appears 150 ms before the target

SOA = 0
cue appears with the target

Positive SOA
cue appears 150 ms after the target

Figure 2. Schematic representation of a trial in Experiments 1 and 2. Participants were instructed to respond with the left or right hand, depending on the colour of the target—a green or red diamond pair. They should ignore the irrelevant cue, which could appear either left or right with respect to the fixation point. The cue could appear before the target (negative SOA), simultaneously with the target (SOA = 0 ms) or after the onset of the target (positive SOA). Congruency is defined as the spatial relationship between the location of the cue and the hand designated by the target signal. See text for further details.

SOAs) the target that conveys the relevant information (see Figure 2). No mask was used, to avoid potential confounds (see the discussion section). The subjects had to respond with the right or the left hand as a function of the colour of the target (the imperative stimulus conveying the relevant dimension). In order to avoid an attention shift back to the centre after the presentation of the cue, we used bilateral targets.

If the cue and the target are presented simultaneously, we can expect a regular Simon effect on RT. If the cue is presented just before the target, we can still expect a positive Simon effect, and its magnitude should decrease as the interval between cue and target (SOA) increases. At long negative SOAs, we can in fact expect the Simon effect to be reversed, especially for the long RTs. Likewise, when the cue is presented just after the target, we can expect a positive Simon effect. This effect should decrease in magnitude as the interval between target and cue increases, but, in this case, not because of an increased suppression, but because of a lack of initial activation. With long positive SOAs, we therefore expect no Simon effect for the short RTs (if the cue is presented 300 ms after the target, RTs faster than 300 ms will obviously not be affected by the cue) and a positive Simon effect for longer RTs. Critically, if the decrease (and reversal) of the Simon effect on the mean RT for negative SOAs is due to the same selective suppression process evidenced in the Simon task (at SOA 0), then we may predict a correlation between the SOA effect observed on mean RT and the SOA effects observed *within* the distribution with the delta-plots technique. In other words, the dynamics observed within the distribution might explain what is typically observed in the mean RT.

GENERAL METHOD

Participants

Thirty-two undergraduate students (22 females, 10 males, mean age 21 years) of the University of Amsterdam, 16 in each experiment, participated to fulfil course requirements. All subjects reported to be healthy and had normal or corrected-to-normal vision.

Apparatus and signals

Signals were presented on a black computer screen with a refresh rate of 100 Hz (see Figure 2). A fixation stimulus consisted of a centrally presented small white square (2 × 2 mm). The task-relevant target signal consisted of a pair of diamonds (1 × 1 cm each) presented bilaterally 1.50 cm to the left and to the right of central fixation. The two diamonds could be either green or red. Viewed at a distance of 60 cm, the target was contained in 5° visual angle. The target remained on the screen for 800 ms. The task-irrelevant cue signal consisted of four small white bars (two vertically aligned bars of 0.24 × 0.32 cm and two horizontally aligned bars of 0.32 × 0.24 cm), configured as the outer ends of a single cross and was presented either 0.82 cm to the left or to the right of fixation. The cue could precede the target at different stimulus–onset asynchronies (negative SOAs), could be presented simultaneously with the target (SOA 0 ms) or could follow the target (positive SOAs; see specific method sections for more details). The cues were presented for 50 ms. The ‘‘Q’’ and the ‘‘P’’ keys on the computer keyboard respectively recorded responses with the left and right index fingers. To avoid strategic anticipation related to SOA, the interval between the preparatory signal (i.e., the fixation square) and the first (task-relevant or task-irrelevant) signal was varied between 500 ms and 1300 ms in such a way that duration of this preparatory interval was not correlated with the subsequent SOA.

Procedure

Subjects were asked to press either the ‘‘Q’’ or ‘‘P’’ keys of the keyboard, depending on the colour of the diamond pair, as fast and as accurately as possible. The colour-to-response mapping was balanced across subjects. Each trial started with the presentation of the fixation point, which served as a warning signal. The location of the cue, left or right with respect to the fixation point, was determined randomly, but evenly distributed. A congruent trial was operationalised by presenting the cue on the same side as (i.e., ipsilateral to) the response designated by the target. An incongruent condition was operationalised by presenting the cue on the side opposite to (i.e., contralateral to) the designated response. The targets were displayed for 800 ms. After these 800 ms, the screen went black for 1000 ms, after which the preparatory fixation signal of the next trial occurred.

Data processing

In addition to analyses of overall performance (accuracy and mean RT), distribution analyses were performed. All individual single-trial RTs were rank ordered, and these RT distributions were then ''vincentised'' (Vincent, 1912; see also Jianq, Rouder, & Speckman, 2004; Rattcliff, 1979), meaning that the distributions were binned into quantiles of equal frequencies (same number of trials), and subsequently the mean RT of each of these quantiles was computed. This was done for each subject and each experimental condition separately. From these distributions, delta-plot values for congruency were determined by plotting the difference between congruent and incongruent RT for each quantile as a function of the mean RT of the two conditions. Finally, the slopes of the delta values were computed by fitting a linear regression to the values across quantiles.

Because percentages cannot be submitted to ANOVA directly, as the means and variances of percentages tend to be closely related, error rates were arc-sine transformed before being analysed (Winer, 1971). In all the reported ANOVAs, the error term was the interaction between the factor ''subject'' and the factor under analysis. When necessary, the degrees of freedom were adjusted by Huynh-Feldt ε correction in order to take sphericity violations into account. For the sake of clarity and convenient reading we report uncorrected *df*s, but the reported *p*-values are based on ε corrected *df*s.

EXPERIMENT 1

The dynamics of the temporal overlap between activations originating from target and distractor are crucial in determining the magnitude (and polarity) of congruency effects (for a review, see Lu & Proctor, 1995). Since it was difficult to estimate a priori which SOAs were most representative in our task, we decided to use a broad range of SOAs.

Specific method

In the first experiment, 15 SOAs were used, ranging from –400 ms to +300 ms in steps of 50 ms. Subjects performed 12 blocks of 180 trials each. Each SOA was represented 12 times in each block of trials, containing six congruent and six incongruent trials, with each congruency condition consisting of three red and three green signals. The duration of one block was about 9 min so that an experimental session lasted about 2 hours, including two breaks of 10 min after every four blocks. The left and right responses were merged. We thus obtained 72 data points per SOA and per congruency. Five bins were used for Vincentisation.

Results and discussion

The mean RTs and error percentages obtained in Experiment 1 are presented in Table 1.

Accuracy. The analysis revealed no significant main effect of congruency on error rate, $F(1, 15) < 1$. In contrast, SOA had a main effect on error rate, $F(14, 210) = 5.86$, $\varepsilon = .906$, $p < .001$, and these two factors interacted significantly, $F(14, 210) = 4.08$, $\varepsilon = .963$, $p < .001$. The direction of effects was similar to those on RT (as reported below), thus rendering an explanation of the results in terms of speed–accuracy tradeoff unlikely.

Mean RT. There was no significant main effect of congruency on RT, $F(1, 15) < 1$, but the main effect of SOA was significant, $F(14, 210) = 37.59$, $\varepsilon = .302$, $p < .0001$. The interaction between congruency and SOA, displayed in Figure 3, was marginally significant, $F(14, 210) = 1.63$, $\varepsilon = .722$, $p = .10$. The fact that congruency effects were generally small and not significant does not necessarily imply a lack of meaningful patterns, however, as will become evident from the distributional analyses reported next.

Delta-plot slopes. A main effect of SOA, also displayed in Figure 3, was found on delta-plots slopes, $F(14, 210) = 3.18$, $\varepsilon = .641$, $p < .01$. In order to check the extent to which the modulation of congruency effects by SOA and the delta slopes involve common mechanisms, the correlation between the mean slope values and the mean congruency effect across SOAs was computed. This analysis revealed a clear correlation between these two indices, $r(13) = 0.76$, $p < .01$. Although analyses of individual subjects are rarely reported, we also analysed this correlation on a subject-by-subject basis. This revealed that the correlation was significant for 11 subjects among the 16. Individual results are given in Table 2.

The overall analysis of behaviour confirmed the presence of a negative congruency effect for negative SOAs: Error rate was higher and RT was slower for congruent than for incongruent trials for negative SOAs, whereas the reverse was obtained for positive SOAs. Changes in delta-plot slopes were also observed across SOAs, indicating that the effect size of congruency is affected by both the time between cue and target and by the RT length. Moreover, these dynamics in congruency effects on RT and in the delta-slope values showed a reasonably strong correlation, suggesting that changes in congruency effect and changes in slopes have a common cause. The dynamics of the effect revealed that the reversal occurs around SOA 0. In order to explore these dynamics in more detail, a second experiment focused on SOAs around 0, allowing us to collect more data per SOA and therefore to perform the distributional analyses with higher precision.

TABLE 1

Mean RTs (rounded to the nearest ms) and error percentages for congruent and incongruent trials for each SOA in Experiment 1

	Stimulus–onset asynchrony														
Trial type	*–400*	*–350*	*–300*	*–250*	*–200*	*–150*	*–100*	*–50*	*0*	*50*	*100*	*150*	*200*	*250*	*300*
Reaction time															
Congruent	371	366	367	373	373	382	394	400	397	398	400	401	398	396	396
Incongruent	368	371	366	366	372	382	391	398	403	405	409	402	401	398	398
Congruency effect	–4	5	–1	–7	–2	1	–4	–3	6	7	10	1	3	2	2
Error percentage															
Congruent	4.4	4.9	4.9	4.7	5.8	6.0	5.8	4.5	0.9	3.3	2.5	2.4	2.4	2.7	2.5
Incongruent	4.7	3.8	3.6	3.1	4.2	4.1	5.2	5.9	4.8	3.1	3.0	3.4	3.0	3.2	2.5
Congruency effect	0.3	–1.1	–1.3	–1.6	–1.6	–1.9	–0.6	1.4	3.9	–0.2	0.5	1.0	0.6	0.5	0.0

Congruency effect = incongruent – congruent.

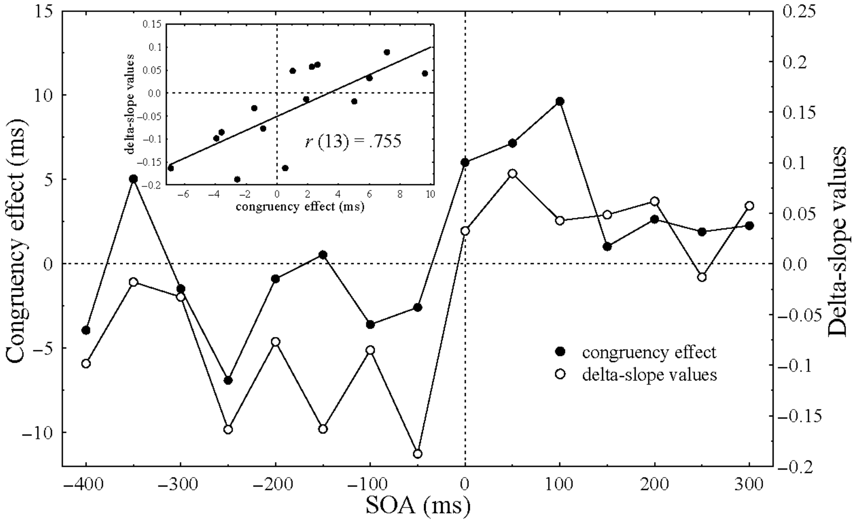


Figure 3. Representation of the congruency effect (thick line) and the slope values of the delta plots (thin line) as a function of SOA in Experiment 1. The correlation plot shows the positive correlation between the congruency effect and the slope value.

EXPERIMENT 2

In the second experiment, we focused on the SOAs around which the reversal of the congruency effect seemed to occur. This also allowed us to record more data per SOA, and hence to have a better estimate of the RT distributions. However, to keep the two experiments as comparable as possible in all other respects, we used the same range of SOA (from –400 ms to +300 ms), but with only few occurrences of the long SOAs (see below).

Specific method

In this experiment we focused on SOAs ranging from –150 ms to +150 ms with a 50 ms step. The other SOAs, hereafter referred to as ‘‘discarded SOAs’’, were preserved in order to keep the context comparable with the first experiment. The distribution of trials was as follows. An experimental block consisted in 184 trials: 168 trials with a SOA in the –150 to +150 ms range. For each ‘‘analysed SOA’’, 24 trials were presented, 12 congruent and 12 incongruent. The two target colours were also equiprobable. The remaining 16 trials (discarded SOAs) were distributed as follows. Each SOA occurred twice. One of the trials was congruent and the other one was incongruent. In parallel, the target was green on one trial, and red on the other. Therefore, the probability of congruent and incongruent trials, as well as the probability of green and red targets, was the

TABLE 2
Within-subject correlations between congruency effects and delta-plot slopes across SOAs in Experiment 1

Subject	*r*
1	.58*
2	.27
3	.16
4	.79**
5	.67**
6	.72**
7	.54*
8	.91**
9	.65**
10	.69**
11	.57*
12	.29
13	.14
14	.69**
15	–.04
16	.53*

*$p < .05$; **$p < .01$.

same. Subjects performed 12 experimental blocks yielding 144 trials per elementary conditions. Nine quantiles were used to Vincentise the distributions.

Results and discussion

Experiment 2 essentially replicates what was observed in the first experiment. Table 3 lists mean RTs and error percentages obtained in Experiment 2.

Accuracy. The analysis on the arc-sine transform revealed no significant congruency effect on error rates, $F < 1$. A main effect of SOA was clearly present, $F(6, 90) = 13.34$, $\varepsilon = .755$, $p < .001$. These two factors interacted significantly, $F(6, 90) = 4.45$, $\varepsilon = .897$, $p = .001$. Again, the direction of effects was such that an explanation in terms of speed–accuracy tradeoff can be discarded.

Mean RT. As shown in Figure 4, there was a main effect of congruency on RT, $F(1, 15) = 9.58$, $p < 0.01$, as well as a significant main effect of SOA, $F(6, 90) = 24.77$, $\varepsilon = .652$, $p < .001$. These two factors interacted significantly, $F(6, 90) = 5.37$, $\varepsilon = .997$, $p < .001$.

TABLE 3
Mean RTs and error percentages for congruent and incongruent trials for each SOA in Experiment 2

	Stimulus–onset asynchrony						
Trial type	*–150*	*–100*	*–50*	*0*	*50*	*100*	*150*
Reaction time							
Congruent	378	381	383	387	390	391	389
Incongruent	373	382	388	396	399	396	397
Congruency effect	–5	1	5	9	10	5	8
Error percentage							
Congruent	6.6	7.3	4.5	3.5	2.3	2.4	2.5
Incongruent	4.5	5.0	5.3	3.6	3.1	3.0	3.0
Congruency effect	–2.1	–2.3	0.8	0.1	0.8	0.6	0.5

Congruency effect = incongruent – congruent.

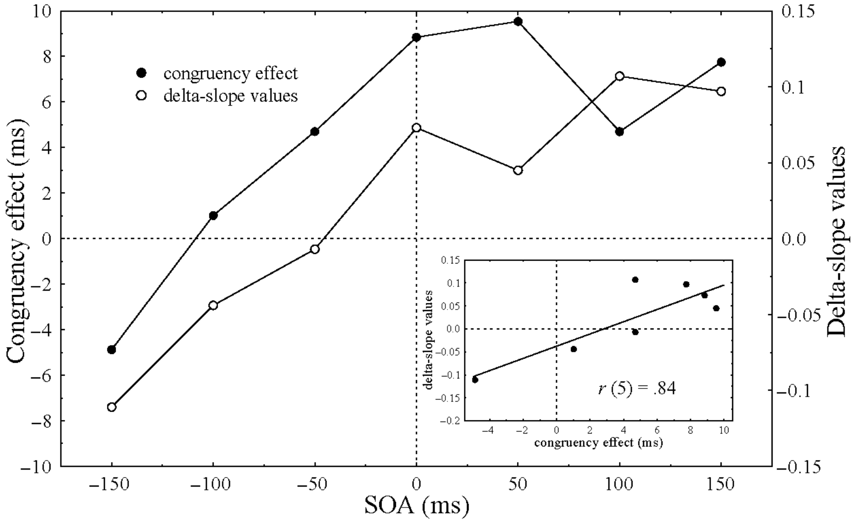


Figure 4. Representation of the congruency effect (thick line) and the slope values of the delta plots (thin line) as a function of SOA in Experiment 2. The correlation plot shows the positive correlation between the congruency effect and the slope value.

Delta-plot slopes. The analysis revealed a main effect of SOA on the slope values, $F(6, 90) = 5.15$, $\varepsilon = 1$, $p < .001$, as shown in Figure 4. As in the previous experiment, the correlation between the delta-slope values and the congruency effect across SOAs was reliable, $r(5) = .84$, $p < .05$ (see Figure 4, inserted panel). Figure 5 presents the delta plots for the seven SOAs. Inspection of Figure 5 reveals several interesting aspects. First, one can see that the fastest responses (the first quantile) always show positive or null congruency effects. Negative congruency effects are never observed for the first quantile; only long RTs present a negative congruency effect. Second, this initial congruency effect for fast responses was larger for SOAs that were associated with flat or negative-going delta plots than for SOAs associated with positive-going delta plots. This is confirmed by a significant linear trend obtained on the delta values of the first quantile, $F(1, 15) = 4.96$, $p < .05$. Such a relationship was also apparent in the first experiment (data not shown).

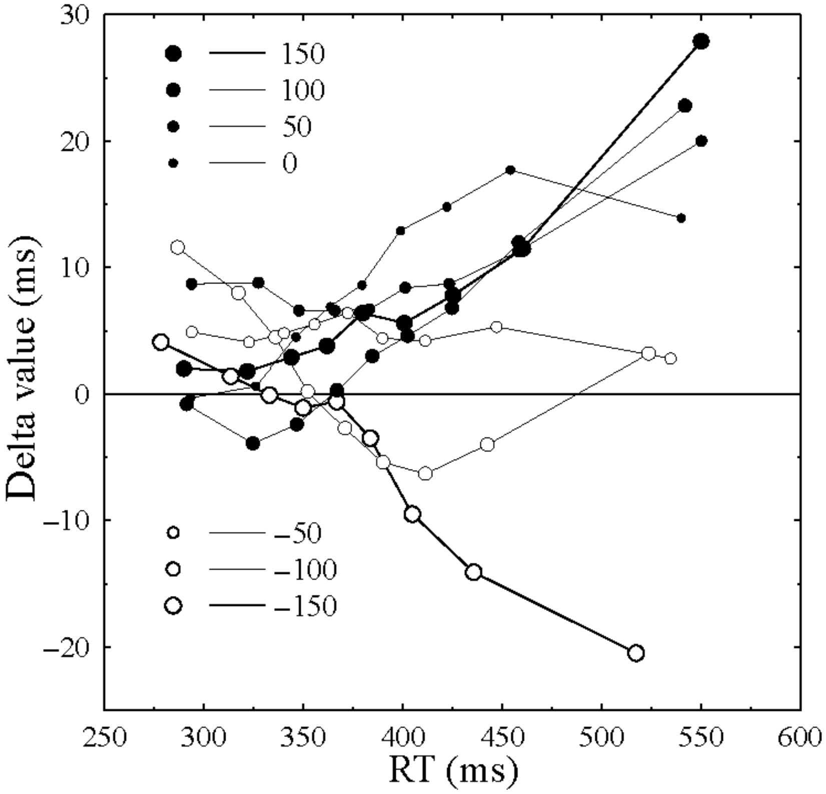


Figure 5. Delta plots per SOA in Experiment 2.

The results of Experiment 2 essentially replicate Experiment 1. A clear reversal of the congruency effect at negative SOAs was observed for both RT and accuracy. Increasing the number of trials per condition yielded even more pronounced results, and allowed for a better estimate of response dynamics as revealed by the distribution analysis. The high correlation between the congruency effect and the delta-plot slopes across SOAs illustrates the stability of this result.

So far, we have only looked at response dynamics as a function of *post-target* time. However, response activation, at least initially, may not be triggered by the target, but by the cue. In order to track the activation-suppression dynamics relative to the cue, the time course of the congruency effect was plotted as a function of the interval between the cue and the response (if the SOA is equal to, let say, –150 ms and the RT to 353, then the interval between the cue and the response is 503 ms). Figure 6 shows the congruency effect recoded in respect of cue–response interval in Experiment 2, and the equivalent range of data from Experiment 1. Once rescaled in time, we computed the mean congruency effect obtained per quantile, from 180 to 660 ms for Experiment 2, and from 40 to 840 ms for Experiment 1. As one can see, an initial facilitation of the congruent response by the cue is observed, expressed by a positive congruency effect peaking around 400 ms. After this point, the congruency effect decreases very strongly, and very steeply, and turns negative for longer intervals. We shall now discuss the functional consequences of these results.

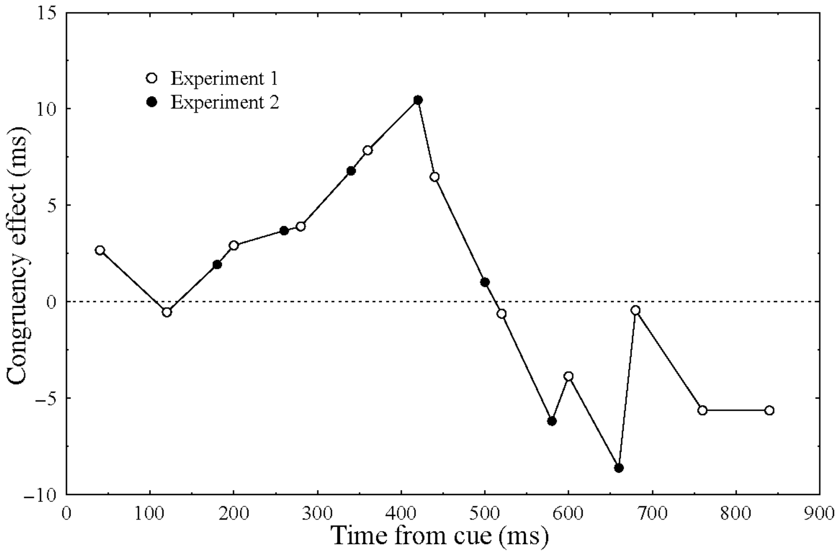


Figure 6. Mean congruency effect plotted as a function of time from cue in Experiments 1 and 2.

GENERAL DISCUSSION

In the literature concerning the processing of irrelevant or conflicting information, two independent lines of research have led to similar theoretical constructs to explain the observed RT data. On the one hand, comparing the mean RTs between condition across different SOA in cue-priming procedures (masked priming, or inhibition of return protocols) has evidenced an ‘‘activation-followed-by-inhibition’’ pattern. When a cue precedes a target, without conveying task-relevant information about the forthcoming target, a facilitation of the processing of the target is observed when the cue and the target convey similar information. This facilitation is characterised by relatively fast responses to targets following the cue at short SOAs. When the interval between the cue and the target increases, the opposite pattern is observed, however: RTs are longer when the cue and the target convey the same information than when they do not. This has been interpreted as reflecting an ‘‘activation-followed-by-inhibition’’ pattern (e.g., Eimer, 1999). On the other hand, when comparing the RT distributions without explicit SOA manipulation, the congruency effect in the Simon task (Simon, 1990) has been shown to decrease (Hommel, 1993; de Jong et al., 1994), and can even reverse (Burle et al., 2002) as poststimulus time increases. The dynamics of this decrease are best studied with RT distribution analytical techniques. One such approach, using delta-plot analysis as a summary, has led to the interpretation of the decreasing Simon effect in terms of an activation-suppression mechanism (Ridderinkhof, 2002a). In the present study, we evaluated whether the two approaches (SOAs manipulations and RT distribution analysis), that both led to activation-and-subsequent-suppression hypotheses, have similar grounds. To this aim, we designed a task combining the cue-priming and Simon protocols. We capitalised on the ‘‘accessory’’ version of the Simon task developed by Simon and Craft (1970). In this task, the presence of an accessory lateralised stimulus influenced performance, although it is completely irrelevant for the task (see introduction for a description of the original task). In the present study, subjects had to respond as a function of the colour of a bilaterally presented target stimulus. Although completely irrelevant for the task, another signal was presented laterally. As in the experiment of Simon and Craft, the position of this irrelevant stimulation (the cue) affected performance when it was presented simultaneously with the target: RT was faster, and error rate lower, when the cue was presented ipsilateral to the correct response, than when it was presented on the opposite side. Therefore, the stimulus display for SOA 0 constituted the essence of a Simon task.

Interestingly, using different SOAs, the relevant and irrelevant stimulus attributes could be separated in time. When the irrelevant attribute was presented before the relevant one, RT was faster, and error rate lower, when the cue was presented on the side *contralateral* to the correct response. We thus obtained a negative congruency effect for negative SOAs. In this respect, the present task allowed us to study the dynamics of the cue-priming effect. Therefore, our first goal, to design a task allowing study of Simon and cue-priming effects, was accomplished. We now turn to our second goal (i.e., evaluating whether similar phenomena are at work in the cue-priming and Simon tasks).

Cue-priming and Simon tasks: Similar suppression mechanisms?

As discussed above, the analysis of mean RT and of error rate revealed a negative congruency effect for negative SOAs, basically replicating results obtained using subliminally presented cues and results obtained in the IOR task. RT distribution analyses revealed that the dynamics of the congruency effect within the RT distribution was also largely affected by SOA: The delta-plot slopes were more negative for negative than for positive SOAs. Most importantly, the mean congruency effect and the slopes of the delta plots appeared to be highly correlated. What does such a correlation tell us about the underlying mechanisms?

As we can see from the insets of Figures 3 and 4, null-congruency effects are associated with a negative delta-plot slope (see also Figure 1). The absence of a congruency effect on the mean RT is thus not necessarily due to equality of the two distributions, but in this case more likely reflects an initial positive congruency effect at fast RTs which turns toward a negative effect as RT lengthens. Close inspection of Figure 4 reveals that, globally, for negative SOAs the first deciles show a positive congruency effect, revealing that the cue facilitates the ipsilateral response (a highly similar pattern was obtained for Experiment 1). This initial positive congruency effect quickly decreases and eventually turns negative, revealing a suppression of this initial facilitation. In contrast, for positive SOAs (as well as SOA 0), no such early facilitation was found, suggesting that the fast responses escaped the effect of the cue. Note that, in this protocol, the irrelevant dimension (the cue) is less salient than the relevant information (the target), compared to more regular Simon tasks. As a consequence, the dynamics of the cue effect, through the direct route, might be relatively slower, explaining why the effect of the cue occurs later. The direct route being activated later, its suppression will also start later, explaining the absence of levelling off of the delta plots in these experiments (note however that such a levelling off seems to occur for the last quantile for SOA 0, where suppression might have been fast enough to affect the slowest RTs; see Figure 5). Therefore, it seems that when an initial response activation is evidenced (positive congruency effect for the fast RTs), this initial activation is followed by negative-going delta plots, whereas when no initial activation occurs, the delta plots are positive-going. These positive-going delta plots likely reflect the interfering effect of the cue, occurring later with longer positive SOA. Even if attempts to suppress this activation are not strong enough to reverse the congruency effects across large portions of the RT distribution, traces of such attempts are evident, as the congruency effect obtained for the very last quantile (slowest RTs) covaries nicely with SOA: The congruency effects for the last quantiles are –21, 3, 3, 14, 20, 23, and 28 ms for the SOAs from –150 to +150, respectively. Such a monotonous ordering is in agreement with the idea of an active suppression view, predicting smaller congruency effects for the slow RTs given more suppression. Therefore, so far, the obtained results may be taken to suggest that the reversal of the congruency effect observed for negative SOAs is an exaggeration of the decrease of the Simon effect classically observed in the literature and replicated in the present study for the SOA 0 (see Figure 5). Indeed, there is a smooth shift from positive to negative congruency effect as the SOA moved from positive to negative.

One last set of comments is in order. The task we designed shares some common features with the masked-prime and the IOR tasks. Similarities and differences will now be discussed.

IOR. The link between IOR and Simon tasks is not new. Ivanoff, Klein, and Lupiáñez (2002) concluded from a meta-analysis that IOR and the Simon effect interact. However, this study was concerned with the origin of interference, not by its modulation. The question whether the negative congruency effect (i.e., the IOR properly) and the decrease in the Simon effect are the same remained an open question. The present task shares obvious features with IOR, but there is also a major difference. In IOR the target is presented at the cued position on half of the trials, whereas in our case the target is *always* presented at the cued location (along with the opposite location). It is therefore never in the interest of the subject to move attention away from the cued location. Therefore, at minimum, the present data comprise an extension of basic IOR results. It might be useful to verify whether the same type of pattern is also observed in a regular IOR task.

Masked-prime tasks. The first obvious difference between our task and the masked-prime procedure is the fact that the cue is perfectly visible in our task. Indeed, in the masked-primed procedure, it has been argued that negative compatibility effects occur only when the subject is unaware of the nature of the prime (Eimer & Schlaghecken, 2002; Klapp & Hinckley, 2002). As a matter of fact, when the mask was removed, only positive compatibility effects were observed (Klapp & Hinckley, 2002). However, Lleras and Enns (2004) have recently challenged this awareness hypothesis. Depending on the mask used (sharing either some or no features with the prime) but at equal levels of visibility, they obtained positive or negative compatibility effects, respectively. The detectability of the prime is therefore irrelevant for the direction of the compatibility effect. Lleras and Enns went one step further, claiming that in the masked-priming procedure the negative compatibility effect has nothing to do with the prime, and it is mainly due to the mask, making the choice of the mask extremely important. The absence of mask stimuli in the present experiments prevents this type of problem.

The fact remains, however, that when no mask was presented Klapp and Hinckley (2002) observed only positive compatibility effects, which is at odds with the present results. Although admittedly speculative, we envision two possible explanations for this discrepancy, which are not mutually exclusive, and are rooted in the same important difference between the two protocols. In our experiments, multiple SOAs were used, as opposed to the single SOA used in Klapp and Hinckley's experiments. As a result of using a single SOA, the dynamics of the effect remain largely unexposed. It is conceivable that the suppression timing is highly context dependent. Several arguments in support of this view can be found in the IOR literature (see Klein, 2000; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001, for a discussion). Should suppression for instance occur later in the absence compared to presence of a mask stimulus, then the reversal of the compatibility effect might remain unrevealed with only a single SOA. The second direct consequence of the use of a large number of SOAs in our task is to introduce a temporal uncertainty not present with only one SOA. Such a temporal uncertainty may have encouraged the subjects to suppress more the irrelevant information, as keeping it active may have increased the probability of an error. Additional work is needed to clarify this point.

In conclusion, we have designed a task that allowed us to study the dynamics of the activation and the subsequent suppression of responses based on task-irrelevant spatial information. The results suggest that similar mechanisms are at play in the reduction of the Simon effect as response time increases and in the reverse compatibility effect obtained in cue-priming tasks.

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