



**The relation between stop signal inhibition and
other forms of inhibition:
A search for common mechanisms**

Frederick Verbruggen

Promotor: Prof. Dr. A Vandierendonck

Proefschrift ingediend tot het behalen van de academische graad
van Doctor in de Psychologische Wetenschappen

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CHAPTER 1

INHIBITION AND THE STOP SIGNAL PARADIGM

INHIBITION: A DEFINITION

The ability to suppress irrelevant or interfering stimuli or impulses is a fundamental executive function essential for normal thinking processes and, ultimately, for successful living (Garavan, Ross, & Stein, 1999, p. 8301).

One thing that immediately attracts attention in the above description is the importance of inhibitory processes. It would be hard to imagine life without the ability to stop walking, talking, or thinking at certain things. So-fortunately-in the past researchers have not only focused on investigating how people can respond and do certain things, but also how these same people can avoid responding or doing things. Inhibition as a safe keeper!

In general, in the psychological literature, the concept 'inhibition' refers to two different constructs. Firstly, there is 'inhibition' in a neurological context or in the context of modelling cognitive processes (e.g., connectionist models) and inhibition refers to the function of neurons that could be excitatory or inhibitory in nature. In a sense, 'inhibition' is related here to the net activation of cells and how cells can activate or inhibit each other by means of, for example, spreading activation and lateral inhibition. The second meaning refers to what is described in the above quote: The ability to suppress thought and behaviour. In the present doctoral thesis, we will focus on inhibition as a set of functions that allow us to suppress for example unwanted thoughts, irrelevant stimulus features and inappropriate responses.

INHIBITION IN COGNITIVE PSYCHOLOGY: CONCEPTS AND THEIR RELATIONS

Although much has been said about the concept of inhibition in the psychological literature, one can argue that still little is known about the fundamental basics of the concept. An important shift that has taken place in the research about inhibition concerns the suggestion that the concept of inhibition would rather be a set of functions than of a unitary construct (Dempster, 1993; Nigg, 2000). Of course, this set or family of functions would imply that there are commonalities, but also differences between the different inhibitory functions.

Nigg (2000) proposed a taxonomy based on a reading of the literature, and distinguished between two main forms of inhibition: (1) effortful inhibition of a motor response or cognitive response and (2) automatic inhibition of attention. Each form of inhibition is further subdivided. In Table 1.1, the different inhibitory systems according to Nigg are presented (Nigg, 2000, p.228). A prominent form of effortful inhibition is 'interference control'. Interference control refers to '*suppressing a stimulus that pulls for a competing response so as to carry out a primary response, to suppressing distractors that might slow the primary response, or to suppressing internal stimuli that may interfere with the current operations of working memory*' (Nigg, 2000, p.222). Examples of interference control can be found in the flanker task (Eriksen & Eriksen, 1974) and the Stroop task (Stroop, 1934) in which the relevant stimulus attribute is accompanied by irrelevant distracting information. Later in this thesis, we will come back to these tasks. As stated by Nigg, '*keeping unwanted thoughts out of mind/working memory*' can also be regarded as some kind of interference control. To make a distinction from the suppression of a response or distractor, as stated above, Nigg uses the term 'cognitive inhibition' to describe this kind of interference control (Nigg, 2000, p.223). Cognitive inhibition is for example operationalized in the directed forgetting paradigm (Bjork, 1972) in which participants are instructed to forget previously learned lists. The third form of inhibition,

'behavioural inhibition', is probably also one of the most fundamental forms of inhibition and refers to the *'deliberate control of a primary motor response in compliance with changing context cues'* (Nigg, 2000, p.223). The stop signal paradigm (Lappin & Eriksen, 1966; Logan & Cowan, 1984), that is the 'backbone' of this doctoral thesis, operationalizes this kind of behavioural inhibition—although we will refer to it as response inhibition. Below, this paradigm will be discussed more into detail. A fourth and last form of effortful inhibition is 'oculomotor inhibition'. *'Suppressing or inhibiting oculomotor movements'* is regarded as a different kind of inhibition by Nigg (2000, p.227) because of the fact that it constitutes a field of its own in the literature. Later on, we will see that not everyone agreed on this latter suggestion. The antisaccade task (Hallet, 1978) in which participants have to suppress reflexive eye movements is an example of an oculomotor inhibitory task.

Table 1.1: The taxonomy of inhibitory systems in cognitive psychology (Nigg, 2000, p.228)

Effortful inhibition of a motor or cognitive response

- (1) Interference control: Prevent interference due to resource or stimulus competition
- (2) Cognitive inhibition: Suppress nonpertinent ideation to protect working memory/attention. Negative priming is considered as an automatic form of cognitive inhibition.
- (3) Behavioural inhibition: Suppress a prepotent-automatic or prepared response or suppress a cued but socially inappropriate response.
- (4) Oculomotor inhibition: The effortful suppression of reflexive saccades.

Automatic inhibition of attention

- (1) Recently inspected stimuli, suppressed for both attention and oculomotor saccade.
 - (2) Information at unattended locations, suppressed while attending elsewhere.
-

In regard to the two automatic forms of inhibition of attention—‘the suppression of recently inspected stimuli’ and ‘the suppression of information at unattended locations’—it suffices for the purpose of the present thesis to say that Nigg based his proposal on Rafal and Henik (1994). These latter authors suggested that in the orienting of visual attention, there are possibly three different attention-relevant inhibitory processes: (1) inhibition of orienting to unattended locations, (2) inhibition of reflexive orienting in the service of a goal, and (3) inhibition of return (i.e., orienting to a location where previously an uninformative cue was presented).

As mentioned above, the taxonomy of Nigg (2000) can be regarded as a theoretical attempt to describe the different inhibitory functions. Later on, Friedman and Miyake (2004) performed a latent variable analysis to reveal the relations between different forms of inhibition and interference control. Friedman and Miyake made a distinction between three different main forms of inhibition (see Table 1.2), more or less in accordance with the taxonomy of Nigg (2000).

Table 1.2: Three inhibition-related functions according to Friedman and Miyake (2004), with each time the three tasks these authors used for each function.

Prepotent Response Inhibition
Antisaccade task (Hallet, 1978)
Stop signal task (Lappin & Eriksen, 1966; Logan & Cowan, 1984)
Stroop task (Stroop, 1935)
Resistance to Distractor Interference
Eriksen flanker task (Eriksen & Eriksen, 1974)
Word naming (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994)
Shape matching (DeSchepper & Treisman, 1996)
Resistance to Proactive Interference
Brown-Peterson variant (Kane & Engle, 2000)
AB-AC-AD (Rosen & Engle, 1998)
Cued recall (Tolan & Tehan, 1999)

A first form of inhibition is 'prepotent response inhibition', i.e., '*the ability to deliberately suppress dominant, automatic, or prepotent responses*' (Friedman & Miyake, 2004, p.104). 'Resistance to distractor interference' or '*the ability to resist or resolve interference from information in the external environment that is irrelevant to the task at hand*' (Friedman & Miyake, 2004, p. 104) is assumed to be a second form of inhibition. Finally, '*the ability to resist memory intrusions from information that was previously relevant to the task but has since become irrelevant*', or 'resistance to proactive interference', is the third form of inhibition (Friedman & Miyake, 2004, p.105). The most important result of the latent variable analysis was that prepotent response inhibition and resistance to distractor interference appeared to be correlated to each other. On the contrary, none of these two constructs correlated to resistance to proactive interference.

In the present doctoral thesis, 'inhibition' is the central topic. In line with the proposals of Nigg (2000) and Friedman and Miyake (2004), we hypothesized that 'inhibition' can be considered as a set of functions with a certain overlap. We will focus on the relation between these different forms of inhibition, and more specifically, on the relation between response inhibition in the stop signal task and other kinds of inhibition in a whole range of other inhibitory paradigms. However, we will opt for a different method compared to Friedman and Miyake (2004). In the past, combining different inhibitory paradigms has proven to be a useful tool to investigate the relation between different kinds of inhibition. For example, Fuentes and colleagues investigated how inhibition of return (IOR) affected interference effects like the Stroop effect and the flanker effect (Vivas & Fuentes, 2001, and Fuentes, Vivas, & Humphreys, 1999, respectively). They found that IOR influenced those interference effects and suggested that inhibitory tagging in IOR also affects the processing of task irrelevant dimensions of stimuli in the Stroop and flanker task, resulting in less distractor interference. In another study, Hommel (1997) combined interference tasks such as the Simon task, the Stroop task and the flanker task to investigate the relative time course of the different congruency or interference effects.

The basic idea behind combining different inhibitory paradigms is that interactions between tasks that are assumed to reflect some kind of inhibition or interference control could tell us something more about the processes in different tasks, and at the end, about inhibition in general. As will appear in the subsequent section, the stop signal paradigm provides a useful task to investigate the relation between response inhibition and other forms of inhibition.

STOP SIGNAL INHIBITION: AN INTRODUCTION

In the most standard form of the stop signal task, auditory stop signals are occasionally presented during a choice reaction time task (i.e., the *primary task*) with visual stimuli. The stop signal informs participants that they are supposed to withhold their response. When the stop signal is presented shortly after stimulus presentation, participants can easily suppress their response. Alternatively, when the stop signal is presented near the execution of the response, participants are no longer capable of withholding their response. To explain these data, a horse race model was proposed by Logan and colleagues (Logan & Cowan, 1984; Logan, Cowan & Davis, 1984).

THE HORSE RACE MODEL

Performance in the stop signal task is assumed to involve two processes that work against each other. First, there is the *go process*, triggered by the imperative stimulus of the primary task. The moment a stop signal is perceived by the participant, another, competing process is started: The *stop process*. These two processes race against each other—that is why we speak of the *horse race model*. Whether or not a response can be inhibited depends on the finishing time of the two competing processes (see Figure 1.1). When the stop process finishes before the go process, subjects can inhibit their response ($T_g > T_s + t_d$, with T_g the finishing time of the go process, T_s the finishing time of the stop process and t_d the delay between the go stimulus

and the stop signal). On the other hand, when the go process reaches the finishing line before the stop process, subjects will respond despite the stop signal ($T_g < T_s + t_d$). When inhibition succeeds, we speak of 'signal-inhibit' trials, whereas failures of inhibition are typically labeled 'signal-respond' trials. Logan and Cowan (1984) were mainly interested in three different points: (1) measuring the difficulty of the stop signal inhibition, (2) measuring the latency of the stop signal inhibition, and (3) measuring the ballistic component¹ of the process that should be inhibited.

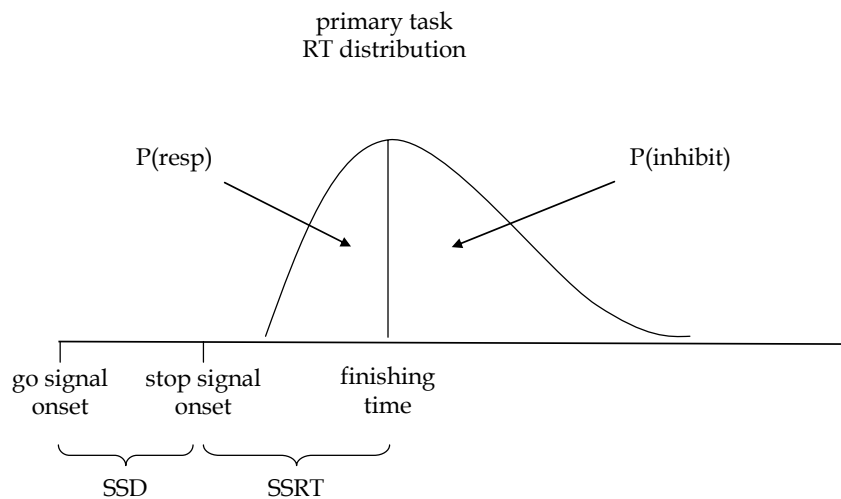


Figure 1.1: Diagram of the horse race model (SSD = Stop Signal Delay).

The horse race model is relatively simple in nature and based on a few straightforward assumptions. An important and core assumption is that the finishing times of the RT processes and the stopping processes are stochastically independent. In other words, these finishing times are

¹ Ballistic processes or the ballistic components of processes are those processes or components that cannot be stopped. Related to this is the 'point of no return' that refers to the point in the processing stream that divides controlled processes from ballistic ones (Logan, 1994).

supposed to be uncorrelated. Besides this ‘stochastic independence’, Logan and Cowan also stated that the stop process and the go process should not influence each other. This ‘context independence’ meant that the performance of the primary task should be the same as in a single-task context without stop signal presentation, and vice versa. Based on these two assumptions, Logan and Cowan (1984) suggested that the stop signal task and the horse race model provide two useful measurements. Firstly, the paradigm allows the observing of the covert latency of the stopping process: The stop signal reaction time. Secondly, the slope of the function in which the probability of responding given a stop signal is plotted against the stop signal delay (the so-called *inhibition function*), gives an index of the variability of the stopping process.

Compared to the inhibition function, the Stop Signal Reaction Time or SSRT is more frequently used in the literature. Several methods for estimating the latency of the stopping process were proposed. Without going too much into detail, the basic idea behind the different methods is that the SSRT reflects the time between the start and the finishing time of the stop process. The start of the stop process is known, since this is the moment in time the stop signal is presented. The finishing time is not directly observed, but it can be derived from the response probability given a stop signal at a certain stop signal delay, and the CRT distribution of the no-signal trials. Given the assumptions of independence of the go process and the stop process, it was proposed that the finishing time of the stop process corresponds to the upper limit of responses that escape inhibition. In Figure 1.1, one can see that the left part of the CRT distribution corresponds to the trials that escape inhibition, the right part corresponds to those trials where responses are successfully inhibited.

The other measurement is the slope of the inhibition function. Logan and Cowan (1984) suggested that inhibition functions that could not be brought into alignment were assumed to reflect differences in inhibitory

control.² However, recent simulations by Band, van der Molen and Logan (2003) suggested that the slope of the inhibition function reflected probably not only differences in the variability of the stopping process. These authors found that the slope was also influenced by the variability in the performance on the primary task, even after the appropriate corrections. Therefore, Band et al. (2003) concluded that the slope of the function was not the ideal measurement to reveal between-group and condition differences in stopping.

On the other hand, these simulations by Band et al. (2003) did demonstrate that under the right conditions (some useful guidelines are provided in their paper, see p.134 et seq.), the stop signal reaction time could reliably be estimated. For example, these authors found that SSRT estimations derived from the central part of the CRT curve were the most reliable. Central SSRT estimations were fairly robust against incidental violations of the assumptions of the horse race model. By using a tracking procedure based on the probability of stopping, these central estimations are used. Such a tracking procedure implies that the Stop Signal Delay (SSD; i.e., the delay between the imperative stimulus and the stop signal) is adjusted after each signal trial, dependent on whether or not the inhibition succeeded. When inhibition fails, the SSD is decreased. After successful inhibition, the SSD is increased. We will use this tracking procedure in the present PhD project. In addition, the two methods used in this PhD project for the estimation of SSRT that will be explained in the different chapters [i.e., (1) the 'integration method' and (2) the method proposed by Logan, Schachar and Tannock, 1997] provided good estimations of the true SSRT.

Beside these two measurements, the stop signal paradigm also offers a method for testing the independence assumptions of the horse race model. It was argued by Logan and Cowan (1984) that the stochastic independence assumption also had important implications for the latency of responses that

² Logan and Cowan (1984) argued that when one compares inhibition functions, transformations that take into account differences in the mean no-signal CRT, the variance of mean no-signal CRT and the variance in SSRT, need to be done first.

escape inhibition (i.e., the signal-respond trials). As can be seen in Figure 1.1, signal-respond RTs are assumed to correspond to the left part of the CRT curve. This implies that the mean signal-respond RT should always be lower than the mean CRT of all no-signal trials. Second, one could predict the mean signal-respond RT on the basis of the CRT curve of no-signal trials. For example, when a participant can inhibit 60% of the responses at a certain delay, then it is predicted that the mean signal-respond RT corresponds to the mean RT of the 60% fastest no-signal trials. It was argued that the independence assumption of the horse race model could be tested by comparing the observed mean signal-respond RT to the predicted mean signal-respond RT, it was argued. This was done several times, with variable success (De Jong, Coles, Logan, & Gratton, 1990; Jennings, Brock, van der Molen, & Somsen, 1992; Logan & Cowan, 1984, van Boxtel, van der Molen, Jennings, & Brunia, 2001). For example, in the study of van Boxtel et al. (2001), there was a significant difference of 23 ms between the observed and predicted signal-respond RTs (although there was no difference between the event related potentials of the signal-respond trials and their corresponding no-signal trials).

In line with the findings of van Boxtel et al. (2001), the simulations by Band, et al. (2003) demonstrated that a mismatch between the observed and the predicted signal-respond RT is probably not the best way to test the independence assumption of the horse race model. It was found that CRT variability and stopping failures on short SSDs affected the difference between observed and predicted signal-respond RTs much more than the dependence between the go and stop process. Therefore, Band et al. (2003) argued that this measurement should no longer be used for testing the independence assumption of the horse race model.

OVERVIEW OF STOP SIGNAL TASK STUDIES

The stop signal paradigm is a very valuable and frequently used paradigm in both clinical and cognitive settings. In this section, I will try to review the most important findings of behavioural, clinical and neuro(psycho)logical studies.

Behavioural studies

A vast majority of the studies that use the stop signal task are behavioural studies with healthy subjects. The stop signal task can be used for discrete hand movements, foot movements (De Jong et al., 1995) or eye movements (e.g., Logan & Irwin, 2000). The stop signal task is also already used for investigating the inhibition of continuous hand movements (Morein-Zamir & Meiran, 2003; Morein-Zamir, Nagelkerke, Chua, Franks, & Kingstone, 2004). Moreover, the stop signal paradigm is not restricted to movements, since it was demonstrated that it could be used to investigate the inhibition of simple thoughts (Logan, 1983) and more complex thoughts (Logan & Barber, 1985). Although it is not easy to find a line in all those studies, roughly spoken there are two groups: One group of studies uses the stop signal paradigm as a tool for investigating processes in the primary task and the other group focuses more on the process of response inhibition itself. For example, in behavioural studies that investigated the process of response inhibition, it was found that stopping latencies were prolonged when response readiness was reduced (van den Wildenberg, van der Molen, Logan, 2002) or related to this, when responses were more forceful (van den Wildenberg, van der Molen, van Boxtel, 2003).

The stop signal paradigm finds its basis in the research on the '*psychological refractory period*' (PRP), which refers to the finding that a response to the second of two successive stimuli is generally slower than the response to the first stimulus. In the study of Vince (1948), participants had to track a line that moved and had to make fast opposite movements when the direction of the line changed. In a sense, this was the first study in which

participants had to stop one movement and replace it by another movement since. The time between changes in direction was manipulated and at the shortest interval, there was sometimes no response to the first stimulus, which was actually in this case a change in direction. Although there was no report of response inhibition in this study, the study of Vince (1948) is usually considered as the precursor of the stop signal paradigm. Later on, Lappin and Eriksen (1966) introduced the term 'stop signal' within the task and they investigated the probability of inhibiting a visual response given the delay between the go signal and the stop signal. Often, this study is now regarded as one of the first studies that used a simple stop task.

The fact that the stop signal paradigm finds its origin in the PRP literature can still be seen when one looks at more recent papers. More specifically, the finding that responses can be inhibited more often when the delay between go stimulus and the stop stimulus is short, led authors to suggest that stopping a response does not suffer PRP interference, unlike selecting or executing a response. This finding was further supported by Logan and Burkell (1986), who used among other things a stop change paradigm. However, it was recently demonstrated by Horstmann (2003) that stopping an ongoing continuous action did suffer from PRP interference, which was not the case with stopping a not-yet-executed action.

We already mentioned that the stop signal paradigm is also used as a tool for investigating processes in the primary task. This was done for a further investigation of blindness effect to response-compatible stimuli (Caessens & Vandierendonck, 2002), the negative priming effect (Verbruggen, Liefoghe, & Vandierendonck, 2005a, Chapter 4 of this thesis), and the switch cost (Verbruggen, Liefoghe, Szmalec, & Vandierendonck, 2005b; Verbruggen, Liefoghe, Vandierendonck, in press b; Chapter 5 of this thesis). These latter studies looked at the effect of stop signal inhibition on the subsequent trial and the common finding was that performance was influenced dependent on whether or not inhibition succeeded. These studies were also partially based on the study of Rieger and Gauggel (1999) who investigated the after-effects of response inhibition (i.e., slower responses after signal trials).

Other studies used the stop signal for investigating the phantom '*point of no return*'. The point of no return refers to the ballistic stage in responding where the response can no longer be inhibited. Several studies used the stop paradigm to determine the ballistic stage—if it exists at all—in response preparation and motor programming (e.g., Osman, Kornblum, & Meyer, 1986, 1990) and continuous tasks of skills like speaking (e.g., Ladefoged, Silverstein, & Papcun, 1973) and typing by experienced typists (e.g., Logan, 1982). In yet another study, Cavina-Pratesi, Bricolo, Pellegrini, and Marzi (2004) used the point of no return within the stop signal task for investigating at what stage the interhemispheric transfer occurred for manual responses to lateralized visual stimuli.

Besides hand and foot movements, the stop signal paradigm is also used to investigate the inhibition of eye movements. Although the principles are similar to those in a simple stop task, stopping saccades is often regarded as a variant of the simple stop task or even as a paradigm on its own. Whereas some researchers just called it a simple stop task with eye movements (e.g., Logan & Irwin, 2000), others referred to it as the 'countermanding task' (e.g., Armstrong & Munoz, 2003; Asrress & Carpenter, 2001; Cabel, Armstrong, Reingold, Munoz, 2000; Hanes & Carpenter, 1999; Hanes & Schall, 1995; Schall, Hanes, & Taylor, 2001). Anyhow, the countermanding task is highly similar to a simple stop task with hand movements: Participants have to stop (in this case a saccadic) response when a stop signal is presented. Stopping latencies can be estimated, just like for hand responses. Several studies that used the countermanding task pointed out, however, that the inhibition of saccadic responses differs from the inhibition of responses with the hand. For example, Logan and Irwin (2000) demonstrated that stopping saccadic responses and stopping responses with the hand were differentially influenced by the compatibility of a stimulus, providing evidence for distinct inhibitory mechanisms for eye movements and hand movements. Moreover, it seems that other brain regions are involved in the inhibition of saccadic and manual responses (e.g., Stuphorn, Taylor, & Schall, 2000).

A final line of behavioural studies focused on the relation between response inhibition and other forms of inhibition or interference control. Kramer, Humphrey, Larish, Logan, and Strayer (1994) found that stopping was more difficult on incongruent trials in a flanker task. Similar results were obtained in similar and other interference or conflict tasks (Ridderinkhof, Band & Logan, 1999; Verbruggen, Liefvooghe & Vandierendonck, 2004, in press a). On the other hand, in a pure stimulus-response compatibility task, the incompatibility of the stimuli did not influence the stopping latencies (Logan, 1981; Logan & Irwin, 2000; van den Wildenberg & van der Molen, 2004). Related to these interactions, Jennings and colleagues (Jennings, 1992; Jennings, Brock, van der Molen, & Somsen, 1992; Jennings & van der Molen, 2002) demonstrated that motor inhibition influenced the regulation of the cardiac cycle in a way that successful inhibition slowed down heart rate.

Variants of the stop signal task

In the most frequent form (cfr. supra), an auditory stop signal is presented during a choice reaction time task and all responses have to be suppressed when the stop signal is presented. Although it is not really a variant of the stop signal task, the go/no-go paradigm is probably the most often used alternative task. The difference between the stop signal paradigm and the go/no-go paradigm lies in the fact that in the latter paradigm, the stop signal or no-go stimulus is always presented at SOA onset 0. Since the go/no-go paradigm can be considered as a paradigm on itself, we will not discuss it here and focus on those response inhibition tasks where the stop signal is always presented after the stimulus of the primary task; in other words, after the go stimulus. The simple stop task, discussed and explained above, involves a rather extreme but simple form of stopping since all responses or processes can be cancelled. Over the years, variants of the stop signal paradigm have been developed in which the stopping process is more complicated, and we will briefly discuss some of them here.

A first variant of the simple stop signal task is the stop change paradigm. Unlike in the simple stop task, the stop signal in the stop change

task informs the participants that a response should be stopped and replaced by another response. In some studies that used a stop change task, participants just had to respond to the stop signal by pressing a key that was not used in the primary task. For example, in the study of Logan and Burkell (1986), participants had to respond with their right hand to the identity of a letter, and when a tone occurred, the right handed response had to be suppressed and replaced by a left handed response, regardless of the identity of the letter. In other studies, participants had to suppress the response to the go stimulus and respond to the identity of the stop signal (e.g., a high or a low tone; Logan, 1983). Yet another kind of stop change task can be found in the study of Band, Ridderinkhof and van der Molen (2003; see also Brown & Braver, 2005, who used a similar task in a neuroanatomical context), in which participants had to change the task in stead of responding to the stop signal. The primary task consisted of responding to the direction of an arrow, and when a stop signal was presented they had to respond to the opposite side.

The selective stop task is another kind of stop task. In this task participants do not always have to withhold their response when a stop signal is presented. Generally, there are two kinds of selective stop tasks: (1) the selective stop task at a motor level and (2) the selective stop task at a perceptual level. In the first variant of the selective stop task, participants only have to stop for example right-handed responses when a stop signal is presented and they can ignore the stop signal in case of a left-handed response (e.g., Logan, Kantowitz and Riegler, 1986; van der Veen, van der Molen, & Jennings, 2000; Verbruggen, Liefoghe & Vandierendonck, 2005a, 2005b). The latter version is based on a perceptual discrimination by using different tones (e.g., only stop when you hear a high tone; e.g., Bedard et al., 2002, 2003). A 'combination' of both variants of the selective stop task is found in the study of van den Wildenberg and van der Molen (2004a; see also van den Wildenberg & van der Molen, 2004b). These authors instructed their participants only to stop their response when the stop signal was presented on the same side of the response.

Note that in regard to the stopping latencies, it is a common finding that making the stop task more complicated results in longer SSRTs for all the above mentioned variants. Actually, this led authors to suggest that there are different mechanisms (De Jong et al., 1995) or different modes (e.g., Logan, 1994; Logan, Schachar & Tannock, 1997) for response inhibition.

Development and aging

Several studies investigated developmental trends in response inhibition in the stop signal task. One of the first studies that looked at age differences with children was the above mentioned study of Schachar and Logan (1990). These authors found that stopping performance was generally better for older children (4th and 6th grade) than for younger children (2nd grade), although this developmental trend did not reach significance. Other studies did find significant differences between age groups. Kramer et al. (1994) observed significant differences between younger and older adults (see also May & Hasher, 1998). These findings were replicated by follow-up studies in which a significant difference between stopping latencies of children and younger adults was found, and these latencies increased again when people grew older (e.g., Carver, Livesey & Charles, 2001; Ridderinkhof, Band & Logan, 1999; Williams, Ponsesse, Schachar, Logan & Tannock, 1999). The same results were obtained with a variant of the simple stop task, namely the selective stop task (cfr. *infra*; Bedard et al., 2002; van den Wildenberg & van der Molen, 2004). On the other hand, Band, van der Molen, Overtom and Verbaten (2001) did not find differences in stopping performance across different age groups. Whereas it was suggested by Ridderinkhof et al. (1999) that response inhibition develops during childhood, Band et al. (2001) argued that a nonselective mechanism of response inhibition seems to be fully developed during early childhood. To conclude, although not every study could find age differences, there is some evidence that there are developmental trends in response inhibition.

Clinical studies and differences between populations

The stop signal paradigm has proven to be a useful tool for investigating the behavioural consequences of certain brain lesions. Rieger, Gauggel, and Burmeister (2003) found that patients with a lesion to the basal ganglia due to cerebrovascular disorders or a brain tumor had slower SSRTs. Similar results were obtained in clinical groups with damage to the right inferior frontal gyrus (Aron, Fletcher, Bullmore, Sahakian & Robbins, 2003), although Dimitrov et al. (2003) found that stop signal inhibition was relatively spared in patients with frontal lobe lesion and only marginally impaired in patients with frontal lobe dementia. Patients suffering from traumatic brain injury (TBI; Rieger & Gauggel, 2002) did not perform worse compared to the control groups. Note that the opposite was found in children with TBI: Konrad, Gauggel, Manz and Scholl (2000) observed a deficit in behavioural inhibition, contrary to the findings with adult subjects that suffer from TBI. Eagle and Robbins (2003a, 2003b) ran some lesion experiments with rats and the stop signal task. These authors found that lesions to the medial prefrontal cortex or the nucleus accumbens core did not influence the stop signal task performance (Eagle & Robbins, 2003a). On the other hand, medial striatal lesions slowed down stopping latencies (Eagle & Robbins, 2003b).

In addition, the stop signal task is used in several studies with different clinical groups. Gauggel, Rieger, and Feghoff (2004) found that patients with Parkinson disease had difficulties with stop signal inhibition, compared to healthy control subjects. Other clinical populations that have shown to have difficulties with response inhibition in the stop signal task are children with epilepsy (Chevalier, Metz-Lutz, & Segalowitz, 2000) or with autism (Geurts, Verté, Oosterlaan, Roeyers & Sergeant, 2004; although the opposite results were found by Ozonoff & Strayer, 1997), subjects with a Posttraumatic Stress Disorder (Casada & Roache, 2005), patients with a focal hand dystonia (Stinear & Byblow, 2004) or mild head injury (Stewart & Tannock, 1999). Badcock, Michie, Johnson, and Combrinck (2002) demonstrated that schizophrenic patients had difficulties with triggering the inhibitory

response, while an fMRI study of Rubia et al. (2001) only found abnormal neural network activation during normal behavioural performance in the stop task. Others have demonstrated that stop signal inhibition was intact in the early stages of the Alzheimer disease (Amieva et al., 2002).

But probably the most investigated clinical group with regard to response inhibition deficits is children with the attentional deficit disorder (ADHD). Schachar and Logan (1990) were one of the first to demonstrate that ADHD children performed worse in the stop signal task compared to control subjects. Later on, this finding was often replicated (mentioning all those studies would lead us much too far, but see Lijffijt, Kenemans, Verbaten & Van Engeland, 2005; Nigg, 2001; and Oosterlaan, Sergeant & Logan, 1998, for some reviews). These observations in the stop signal paradigm and in other tasks that operationalize response inhibition even led some authors to conclude that the deficit in ADHD was primarily a response inhibition deficit (e.g., Barkley, 1997).

Personality characteristics also seem to sometimes influence the stop signal task performance. One personality trait that is often related to poorer response inhibition is impulsivity (Dougherty et al., 2003; Logan, et al., 1997; Marsh, Dougherty, Mathias, Moeller, & Hicks, 2002; but see Rodriguez-Fornells, Lorenzo-Seva & Andres-Pueyo, 2002, who did not find an effect of impulsivity in adult subjects). Probably related to the findings with impulsivity, Nederkroon, van Eijs and Jansen (2004) found that restrained eaters with bulimic symptoms also performed worse in the stop signal task. Finally, in a study where participants had to complete several personality tests, it was demonstrated that higher scores on the Sensitivity to Reward scale and lower scores on the Sensitivity to Punishment scale were associated with general inhibitory deficits (Avila & Parcet, 2001).

Neurophysiological, -anatomical and -pharmalogical studies

A first and often used neurophysiological method is the measurement of event related potentials. De Jong, Coles, Logan and Gratton (1990) were the first to measure the electroencephalogram while participants performed the stop signal task and demonstrated that on successfully inhibited trials,

there was a positive deflection in the waveform of the event-related potential. Also, the amplitude of the lateralized readiness potential (LRP), reflecting motor preparation, was lower on signal-inhibit trials than on signal-respond trials. On the other hand, the amplitude of the LRP on successfully inhibited trials was still larger than the amplitude needed to trigger electromyographic activity in the responding muscles. Others used the same method for measuring electric brain activity (e.g., van Boxtel, van der Molen, Jennings & Brunia, 2001). However, when measuring ERPs in the stop signal task, the signals related to the go process and the signals related to the stop process are intermixed, in a way that the mean of both signals is captured and measured at the scalp site. Recently, Kok, Ramautar, De Ruiter, Band, and Ridderinkhof (2004) proposed a method to distinguish between the two different electrophysiological signals and found a nice distinction between the N2/P3 wave of successful and unsuccessful stop trials. One of the conclusions of that paper was that at the central electrode Cz the P3-component peaked earlier on successful trials, suggesting that this component reflects at least partially the efficiency of inhibitory control. The N2/P3 complex was later on further validated in a study by the same authors (Ramautar, Kok, Ridderinkhof, 2004). Note that the stop-P3 was also found in another study that used a different method, although with a more anterior scalp distribution (Bekker, Kenemans, Hoeksma, Talsma, & Verbaten, 2005). In another recent study that measured the electroencephalogram while participants performed the stop signal task, van Boxtel, van der Molen and Jennings (2005) demonstrated that after signal-respond trials there was an error-related deflection of the ERP wave, probably generated by different parts of the anterior cingulate cortex.

Other studies used neuroimaging techniques like fMRI to reveal the neuroanatomical locus of response inhibition in the stop signal task. In different versions of the stop signal task, Rubia et al. (2001) found common activation in predominantly right hemispheric anterior cingulate, supplementary motor area, inferior prefrontal, and also in the parietal cortices. Furthermore, Rubia and colleagues demonstrated that the right

inferior cortex was (Rubia et al., 2001; Rubia, Smith, Brammer, & Taylor, 2003) activated by response inhibition in the stop signal task.³

A third line of 'neurologically' oriented research, concerns those studies that investigated the effect of psychopharmaca and drugs on response inhibition. One of those substances that is used in the context of the stop signal paradigm, is the stimulant drug d-amphetamine. It was demonstrated that the administration of d-amphetamine led to a better performance on the stop signal task (De Wit, Crean, Richards, 2000; De Wit, Enggasser, Richards, 2002), although Fillmore, Kelly and Martin (2005) could not replicate this effect. Note that Eagle and Robbins (2003a) also found no effect of d-amphetamine on stopping latencies of rats. Another substance that was proven to enhance stopping performance, is Modafinil (Nouraei, De Pennington, Jones, & Carpenter, 2003), which is a wake-promoting agent similar to methylphenidate. Methylphenidate itself also influences SSRTs: Several studies demonstrated that the response inhibition deficit observed in ADHD children disappeared largely when methylphenidate was administered (Aron, Dowson, Sahakian, & Robbins, 2003; Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2005; Konrad, Gunther, Hanisch, & Herpertz-Dahlmann, 2004; Potter, & Newhouse, 2004; Tannock, Schachar, Carr, Chajczyk, & Logan, 1989). Potter and Newhouse (2004) also found similar effects of nicotine. On the other hand, Overtoom et al. (2003) found that inhibition performance of ADHD children was only improved under desipramine (a noradrenalin re-uptake inhibitor) but not under methylphenidate or L-dopa (a dopamine (DA) agonist).

Of course, there are also substances that impair response inhibition. The most obvious substance is alcohol. Mulhivill, Skilling and Vogel-Sprott (1997) demonstrated that response inhibition in the stop signal task was indeed influenced by the administration of alcohol. Later on, it was

³ Note that the right inferior cortex is also activated in the go/no-go paradigm (Bunge, Dudocovic, Thomason, Vaidya, Gabrieli, 2002; Garavan, Ross, Murphy, Roche, & Stein, 2002; Garavan, Ross & Stein, 1999; Konishi et al., 1999), further demonstrating the importance of this region for response inhibition.

demonstrated that behavioural reinforcement, caffeine or a combination of caffeine and reinforcement, counteracted the impairment induced by alcohol (Fillmore, & Vogel-Sprott, 1999) and that alcohol expectancies also influenced the effect of alcohol on stopping latencies (Fillmore & Blackburn, 2002). Other substances that have shown to prolong stopping latencies are cocaine (Fillmore & Rush, 2002; Fillmore, Rush, & Hays, 2002) or the sedative-hypnotic drug triazolam (Fillmore, Rush, Kelly, & Hays, 2001).

So far, we have mentioned different neurophysiological, -anatomical and -pharmacological studies. These studies contributed largely to a better understanding of underlying processes in the stop signal task, leading authors to start hypothesizing about the nature of response inhibition in the stop signal task. Among other things the finding that the amplitude of the LRP on successfully inhibited trials was still larger than the amplitude needed to trigger electromyographic activity in the responding muscles, led De Jong and colleagues to suggest that two different mechanisms were involved in response inhibition: A central mechanism that allows the selective inhibition of the required response, and a peripheral one that inhibits all responses (De Jong et al., 1990; De Jong, Coles & Logan, 1995).

However, not everyone agreed on this distinction between two different mechanisms in the brain, responsible for different kinds of inhibition. Band and van der Molen (1999) argued that a peripheral mechanism of inhibition was incorrectly inferred from electrophysiological measures like the LRP (lateralized event related potential) and EMG data (electromyogram). These authors suggested that inhibitory processes always involve the cortex, and that inhibitory effects are exerted upstream from the primary motor cortex. Furthermore, they made a distinction between possible agents of response inhibition—like the prefrontal cortex and basal ganglia—and the possible sites of inhibition, like the thalamus and motor cortex. Because the basal ganglia are assumed to be part of the medial loop responsible for motor behaviour (cfr. Brunia, 1997), it was hypothesized that cortical and subcortical structures conjointly accomplish response inhibition, with the cortical structures, like the inferior frontal cortex, in charge. Note that several studies

reviewed above are in favour of the proposal of Band and van der Molen (1999).

A final remark that we want to make in regard to the neurological locus of response inhibition in the stop signal task, concerns the role of the right inferior cortex. It seems that the right inferior cortex plays an important role in response inhibition in the stop signal task and different variants of this task. Interestingly, this region also becomes activated in other tasks that are assumed to require different kinds of inhibitory control, like interference tasks such as the flanker task (e.g., Bunge et al., 2002; Hazeltine, Poldrack, & Gabrieli, 2000) and the Stroop and Simon task (e.g., Peterson et al., 2002). This led Aron, Robbins and Poldrack (2004) to suggest that the right inferior frontal cortex plays an important role in inhibition. It is hypothesized to be part of a broader network of other regions like the dorsolateral prefrontal cortex (DLPC) and the anterior cingulate cortex (ACC), helping to resolve different kinds of cognitive ‘problems’.

THE RELATION BETWEEN STOP SIGNAL INHIBITION AND OTHER FORMS OF INHIBITION: A SEARCH FOR COMMON MECHANISMS

In the present doctoral thesis, we will explore more into detail the relation between stop signal inhibition and other forms of inhibition. This will be done by combining the stop signal paradigm with other inhibitory paradigms. In the concrete, the primary task in the stop signal paradigm will no longer be a simple visual primary choice reaction time task but a task that is assumed to require some kind of inhibition. We argue that investigating the effect of the inhibitory primary task and the stop signal performance or inhibition, provides a useful tool for investigating the relation between stop signal inhibition and the particular type of inhibition that is operationalized in that particular task.

There are four empirical chapters. Each chapter consists of one or more empirical studies. The rationale of each study will be explained at the beginning of the chapters, so here we will describe only very briefly the content of each chapter. In Chapter 2, the focus is on the suppression of

irrelevant stimulus features in interference tasks. In Chapter 3, the results of Chapter 2 are linked to the suppression of irrelevant responses in similar interference tasks and we will try to explain why differences are found between different interference tasks. In other words, when we link these two first chapters to Nigg's taxonomy, both Chapter 2 and Chapter 3 investigate the relation between stop signal inhibition or response inhibition, and another form of effortful inhibition, namely interference control. In Chapter 4, the link with negative priming is investigated, and in Chapter 5, the same is done for task switching. Thus, related to the taxonomy of Nigg (2000), these two chapters enclose studies that focus more on the relation between the effortful stop signal inhibition and more 'automatic' forms of inhibition. Another way to put it would be that in Chapters 2 and 3 we look at the effect of conflict or interference and in Chapters 4 and 5 at the after-effects of conflict or interference. We will come back to this issue.

CHAPTER 2

THE INFLUENCE OF STIMULUS INTERFERENCE ON STOP SIGNAL INHIBITION

In this chapter, the effect of stimulus interference or stimulus conflict on response inhibition is investigated. Ridderinkhof, Band and Logan (1999) found when they combined an arrow version of the Eriksen flanker task, that it was harder to inhibit motor responses on incongruent flanker trials. Based on this finding, they suggested that this was due to the fact that stop signal inhibition and selective suppression of the incongruent response in the flanker task interfered with each other.

The congruency effect is commonly observed in the literature about attention and refers to the finding that a response to the relevant stimulus feature is slowed down when this relevant stimulus feature is accompanied by irrelevant and distracting information. For example, in the Eriksen flanker task (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979), participants have to respond to a centrally presented target in the presence of distracting flankers. When these flankers are incongruent with the target, responses are slowed down. This so-called congruency effect in tasks like the flanker task is typically explained by means of a dual-route model (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq & Osman, 1990; Ridderinkhof, van der Molen, Bashore, 1995). Generally, in a dual-route model, the distinction is made between a direct and a controlled route. The relevant stimulus information is assumed to be processed via the controlled route, which is relatively slow since responses are assigned via an arbitrary response mapping. Irrelevant information on the other hand, is processed in a fast and automatic way via the direct route, based on existing stimulus-response links. As a result, two responses become activated and in case of an incongruent trial, this will lead to a conflict. To resolve this conflict, an active inhibition mechanism that would suppress the incorrect response was proposed (Eriksen & Schultz, 1979; Ridderinkhof et al., 1999).

This suggestion of an active inhibitory mechanism was also made more explicit by Ridderinkhof when he proposed the *activation-suppression*

hypothesis (Ridderinkhof, 2002a). The activation-suppression hypothesis holds that the response associated with the irrelevant stimulus feature becomes activated along the direct route and that this response becomes subsequently suppressed by a central and selective response suppression mechanism. This inhibitory mechanism is characterized by the facts that it is (a) active and non-automatic and (b) externally imposed, presumably originating from the prefrontal cortex (Ridderinkhof, 2002a). In Figure 2.1, a schematic presentation of the dual-route model with the selective suppression mechanism is presented.

Thus, Ridderinkhof et al. (1999) suggested that this selective suppression mechanism interferes with motor inhibition in the stop signal task, explaining why stopping responses was disrupted on incongruent trials. Moreover, according to Ridderinkhof et al. (1999), this interaction between both types of inhibition results from the fact that there are probably common mechanisms needed for both types of inhibition (i.e., motor inhibition and selective suppression).

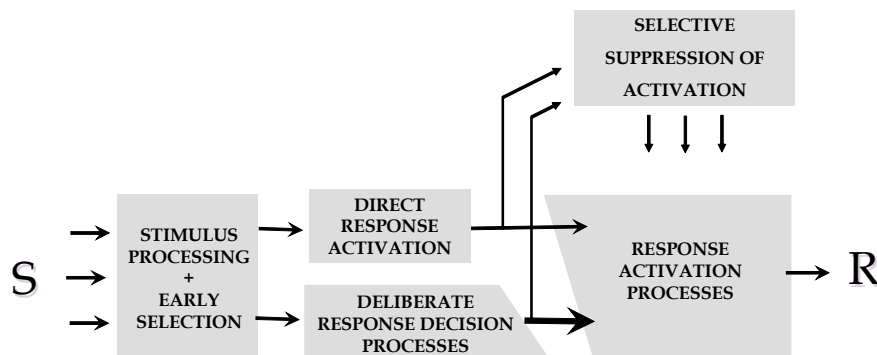


Figure 2.1: The extended dual-route model of Ridderinkhof, 2002a (p. 501).

In the three studies of the present chapter, we started from the ‘common mechanism hypothesis’ of Ridderinkhof et al. (1999) and the activation-suppression hypothesis of Ridderinkhof (2002). Our first research question was whether this selective suppression mechanism can only operate at a response related processing stage. Related to this issue, we wanted to look

whether the activation of incorrect responses in the flanker task is necessary to find an interaction with the stop signal task and the flanker task. In other words, investigating the interaction between selective suppression at different processing levels and stop signal inhibition could tell us something more about (a) the nature of selective suppression in different conflict tasks and (b) the relation between selective suppression and stop signal inhibition.

In the first study, distractors that were categorically related to the targets but that were not part of the response set were introduced. In the absence of a response conflict, we assumed that the conflict was situated at a central processing stage. In the second study, we looked at the effect on irrelevant stimulus features, causing interference at an early processing level, on response inhibition. In the last study of this chapter, we performed a single experiment without the stop signal task in order to find behavioural evidence from another research line or perspective, i.e., the conflict monitoring literature, for the assumption that active selective suppression can occur at different processing levels. The research logic is that when similar intratrial adjustments are made for conflict at different processing levels, such as selective suppression of irrelevant stimulus features, we should also find similar intertrial adjustments.

THE INTERACTION BETWEEN STOP SIGNAL INHIBITION AND DISTRACTOR INTERFERENCE IN THE FLANKER AND STROOP TASK^{4,5}

In the present study, two experiments were conducted to investigate the interaction between the behavioural inhibition, measured by the stop signal task, and distractor interference, measured by the flanker task and the Stroop task. In the first experiment, the stop signal task was combined with a flanker task. Analysis revealed that participants responded faster when the distractors were congruent to the target. Also, the data suggest that it is more difficult to suppress a motor response when the distractors were incongruent. Whether the incongruent distractor was part of the response set (i.e., the distractor could also be a target) or not, had no influence on stopping reactions. In the second experiment, the stop signal task was combined with a manual version of the Stroop task and the degree of compatibility was varied. Even though in the second experiment of the present study interference control is differently operationalized, similar results as in the first experiment were found, indicating that inhibition of motor responses is influenced by the presentation of distracting information that is not part of the response set.

⁴ Verbruggen, F., Liefoghe, B., & Vandierendonck, A. (2004). The interaction between stop signal inhibition and distractor interference. *Acta Psychologica*, 116, 21-37.

⁵ We would like to thank Wery van den Wildenberg, Hartmut Leuthold and Bernhard Hommel for their helpful comments on a previous version of the manuscript.

INTRODUCTION

Inhibition has always been a very popular concept in psychology. Nevertheless, the relation between different kinds of inhibition is still poorly understood. In fact, inhibition used to be conceptualized as a unitary concept, but behavioural, neuropsychological and neurophysiological evidence suggests that a differentiation is more appropriate (e.g., Harnishfeger, 1995). In Nigg's (2000, p. 228) taxonomy for inhibitory systems in cognitive psychology there is a distinction between effortful and automatic inhibition, and both types are further subdivided into different inhibitory functions. In the present research, we will focus on the interaction between different forms of 'effortful inhibition' and more specifically between (1) behavioural inhibition, measured by the stop signal task, and (2) interference control, measured by both a flanker task and a manual version of the Stroop task. Such an interaction could indicate that different forms of inhibition rely on a common mechanism.

The stop signal paradigm (Lappin & Eriksen, 1966; Logan, 1994; Logan & Cowan, 1984) provides a useful measurement of behavioural inhibition. In this task, participants have to execute a speeded choice reaction time (CRT) task. Infrequently (usually on 25% of the trials), a stop signal is presented. The stop signal tells the participants to suppress their response. On short stop signal delays (SSD; the interval between the presentation of the go signal and the stop signal), participants can easily suppress their response. By contrast, when the stop signal delay is long enough, participants will nearly always execute the response. Logan and Cowan (1984) and Logan, Cowan, and Davis (1984) explained those results by a race between two processes: A go process and a stop process. According to their horse-race model, if the stop process is completed before the go process, participants will inhibit their response (*signal-inhibit trials*). When the go process on the contrary finishes before the stop-process, participants will respond (*signal-respond trials*). Based on the assumptions of the horse-race model, it is possible to estimate the covert latency of stopping: The stop signal reaction time (SSRT; for reviews see Logan, 1994, and Band, van der Molen, & Logan,

2003). The stop signal paradigm has already been used with various responses such as manual responses (see Logan, 1994, for a review), foot movements (De Jong, Coles, & Logan, 1995) and eye movements (Logan & Irwin, 2000). Several authors found age-related differences (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Ridderinkhof, Band, & Logan, 1999) and differences in clinical populations such as attention deficit hyperactivity disorder (ADHD; e.g., Jennings, van der Molen, Pelham, Brock, & Hoza, 1997; for a review see Nigg, 2001). Also the simulations by Band et al. (2003) have shown that this estimation can be used to discriminate between groups and conditions.

Until now, few have investigated the relations between the stop signal task and other inhibitory functions or tasks. Only three interactions have been investigated. Firstly, Jennings and colleagues (Jennings, van der Molen, Brock, & Somsen, 1992) found that successful inhibition of motor responses slowed heart rate. The authors concluded that stop signal inhibition and cardiac inhibition may appeal on the same midbrain structures. Second, in several studies no difference between the inhibition of spatially compatible responses vs. spatially incompatible responses has been found (e.g., Logan, 1981). It has been argued that resolving interference of spatially incompatible responses and stopping of behaviour do not interact (Kornblum, Hasbroucq, & Osman, 1990). Logan and Irwin (2000) replicated the null effect for inhibiting manual responses to spatial compatible and incompatible stimuli. However, they did find an interaction between the speed of inhibiting saccadic responses and spatial S-R compatibility, suggesting that eye and hand movements are inhibited by separate processes. Third, two studies found an interaction between the Eriksen flanker task (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979) and the stop signal task using different visual stimuli in the flanker task (Kramer et al., 1994; Ridderinkhof et al., 1999).

In the Eriksen flanker task, participants perform a speeded CRT task to target stimuli (usually letters) which are flanked by distractors. The distractors can be congruent (indicating the same response as the target), neutral (no response assignment) or incongruent (the target requires another response than the distractors). The common finding is that CRTs are larger

when the flankers are incongruent. When flankers are neutral, CRTs may be larger than when flankers are congruent; this is usually interpreted as a facilitation effect. Several models have been proposed to explain such findings (e.g., Eriksen & Schultz, 1979; Miller, 1988; Ridderinkhof, 1997; Ridderinkhof, van der Molen, & Bashore, 1995). The general idea behind these models is that both flankers and target are processed. For example, Ridderinkhof (Ridderinkhof, 1997; Ridderinkhof et al., 1995) proposed that on the one hand the targets are processed via an attentive processing route with a target selection and stimulus-response translation. The flankers on the other hand are processed via a direct priming route: The congruent flankers activate the correct response and incongruent flankers prime an incorrect response. On condition that there is a close temporal overlap between the activation caused by the incongruent flankers and the response evoked by the target, responses are slowed down. Flowers (1990) manipulated the stimulus onset asynchrony (SOA) between flankers and target. With a simultaneous presentation he hardly found a facilitation effect of congruent flankers, whereas incongruent flankers interfered with the targets. However, when flankers are presented 200 ms earlier, targets with congruent flankers are processed faster and the effect of incongruent flankers disappeared.

Interestingly, results of Kramer et al. (1994) and Ridderinkhof et al. (1999) indicate that the SSRT is affected in the same way as the CRT: Stopping is slowed down when flankers are incongruent. In spite of the similarity of the results in both studies, the authors interpreted their results slightly differently. Kramer et al. (1994) stressed the number of responses activated and suggested that it is harder to suppress two responses, in case of incongruent flankers, than one response in case of congruent or neutral flankers. Ridderinkhof et al. (1999) interpreted their data more in terms of an interaction between inhibiting an incorrect response in the flanker task and the suppression of a motor response in the stop signal task. A similar interpretation for the data of Kramer et al. (1994) was provided by Logan (1994), stressing the interaction between the two types of inhibition. Also, Logan, Kantowitz, and Riegler (1986; cited in Logan, 1994) found that the number of responses in the go task had not much influence on the SSRTs of

simple stopping, indicating that the interaction hypothesis of Ridderinkhof et al. (1999) may be more appropriate.

In the present study, it was our purpose to investigate whether the activation of incorrect responses is crucial for the findings in the latter studies by presenting distracting information that did not evoke responses. After all, notwithstanding differences in the interpretations of Kramer et al. (1994) and Ridderinkhof et al. (1999), both groups of authors stressed the fact that the observed interactions occur at the level of response sets.

EXPERIMENT 1

In the present experiment, we presented the participants five arrows and they had to respond to the direction of the central arrow (left or right). There were three types of flankers: Congruent (e.g., both target and flankers pointing to the right) and incongruent flankers that were part of the response set (incongruent RS; e.g., flankers pointing to the right when the target is pointing to the left), like in most studies. In addition, targets could be flanked by arrows with a direction not in the response set (incongruent NRS; arrows pointing up or down). Studies of Shor (1970, 1971) have shown that different directions interfere with each other. Shor embedded the words up, down, left and right in arrows. Participants had to define the direction of the arrows, which was different from the direction indicated by the words. Just like in the original Stroop task, Shor found the typical interference effect, although smaller in magnitude. These findings showed that directions interfere with each other and also suggest that directions are categorically related. Therefore, directions could be used to manipulate the degree of incongruence in a flanker task. After all, besides the effect of response compatibility in the flanker task, as described in the introduction, a few studies (e.g., Flowers & Wilcox, 1982) have found that semantic categorical congruity between flankers and targets has an influence on stimulus classification, whereas both effects are relatively independent. In the present experiment, by introducing flankers that are categorically related to the targets but are not part of the response set, the hypotheses of Kramer et al. (1994) and Ridderinkhof et al. (1999) are both tested. If being part of the

response set is crucial for the interaction between the flanker task and the stop signal task, one would not expect an effect of incongruent flankers that are not in the response set on stopping.

METHOD

Participants

Thirty first-year psychology students (24 females and 6 males) of Ghent University (Belgium) participated for course requirements and credit. All participants had normal or corrected-to-normal vision, were right-handed, and all were naive as to the purpose of the experiment. One participant was excluded from further data-analysis because of waiting strategies (based on SSDs, probabilities of responding and SSRTs).

Apparatus and signals

The experiment was run on a Pentium III PC. Stimuli were presented on a 17-inch monitor, placed at 50 cm distance in front of the participants. Each stimulus was composed of five arrows, placed next to each other. The target arrow pointed always to the left or the right. The direction of the flankers could be left, right, up or down. There were three flanker conditions: Congruent, NRS Incongruent (flankers that are not part of the response set) and RS Incongruent (flankers that are part of the response set). In order to keep the materials as close as possible to those of Ridderinkhof et al. (1999), the visual angle subtended by the flankers we used, approximated $1^\circ \times 1^\circ$. The target arrow was a little bit smaller: $0.80^\circ \times 0.80^\circ$. The five arrows subtended together horizontally a visual angle of 5.6° . The solid filled white arrows (equilateral triangles) were presented at central location on a black background in a rectangle ($7.5^\circ \times 2.5^\circ$). The rectangle served as fixation area and remained on the screen during the blocks. The arrows were presented during 500 ms and required a response within 1,500 ms after its onset. The next trial was presented 1,500 ms after the response. Responses were collected with a response box connected to the game port of the PC. All participants placed their index fingers from their left- and right hand on the

left and the right buttons of the response box, respectively. Occasionally loud and clear auditory stop signal (750 Hz, 70 dB, 50 ms) was presented shortly after the stimulus onset in the visual primary task.

Tasks and procedure

Participants performed their task in a dimly lit, sound attenuated room. The primary task was to react to the direction of the central arrow. Participants were instructed to respond as quickly and accurately as possible. The three types of stimuli appeared with equal probability. The order of the trials was randomized with the restriction that the target was not identical to the incongruent distractors of the preceding trial. When the flankers were NRS incongruent, the direction (up or down) was randomly chosen with at the end of the experiment approximately as many arrows pointing up as arrows pointing down.

The experiment consisted of two parts, one with stop signals and one without stop signals. In both parts there was a practice phase and an experimental phase. The order of the parts was counterbalanced across participants. Instructions appeared on the screen and participants were informed about the order. For the part without stop signals, the number of practice blocks depended on the order of the parts. When participants started with the part without stop-signals, there were two practice blocks of 48 trials each. When they had already performed the task with stop signals, there was still one 'practice' block of 48 trials to avoid a carry-over of the presentation of stop signals in the previous block on the first trials of the first experimental block. After the practice phase, there were two experimental blocks of 98 trials whereby the first two trials were warm-up trials, excluded from data-analysis. The part with stop signals consisted of two practice blocks of 48 trials each, regardless of the order of the task, and six experimental blocks of 98 trials each with the first two trials as warm-up trials. On a random selection of 25% of the trials, a stop signal was presented. This resulted in 48 stop trials for each flanker condition. The stop signal delay was initially set at 250 ms and was continuously adjusted according to a staircase tracking algorithm (Levitt, 1970) for each type of trial

to obtain a probability of stopping of 50%. This method provides SSRT estimations that are derived from the central part of the no-signal RT curve, with important advantages. Logan, Schachar, and Tannock (1997; see also Band et al., 2003) demonstrated that 'central' estimates are relatively insensitive to violations of the horse-race model and therefore most reliable. For obtaining an approximate probability of 50%, each time the subject responded to the stimulus in the presence of a stop signal, the stop signal delay decreased with 50 ms. On the other hand, after successful inhibition, the delay increased with 50 ms.

In order to avoid 'waiting' strategies, participants were informed about the tracking procedure and that the probability of stopping will approximate 50%, irrespective of whether they were postponing their response or not. Moreover, we adopted the feedback system, used by Ridderinkhof et al. (1999). After each trial, feedback in the form of a digit was presented during 500 ms. The faster participants reacted correctly on no-signal trials, relative to their mean CRT, the more points they earned (ranging from 2 to 5). Incorrect responses only received 1 point, regardless of the speed of responding and non-responding resulted in zero points. On signal trials, participants received 5 points after successful inhibition and 1 point when inhibition failed. At the end of each block, feedback about their mean performance was presented: The mean CRT of no-signal trials and the total of points earned on no-signal trials. The points were only used to inform the subjects and had no further consequences.

Stop latency estimation

SSRTs were estimated as proposed by Logan and Cowan (1984), based on the horse-race model. According to this model, after rank ordering the CRTs of no-signal trials, the left, fast part of this CRT-distribution is assumed to correspond to the distribution of CRTs of signal trials on which inhibition failed. Doing so, the finishing time of the stop process can be derived. The finishing time of the stop process corresponds to the n th CRT of the no-signal trials, where n is the result of multiplying the total number of no-signal trials by the probability of responding when a signal is

presented, given a certain SSD. Since the start of the inhibition process (mean SSD) and the finishing time are known, the SSRT can be estimated. The SSRT is the result of the subtraction finishing time minus start or '*n*th CRT minus SSD' (see Band et al., 2003; Logan, 1994). Besides the estimation of SSRT, mean CRTs of signal-respond trials can be predicted also. This is done by calculating the mean of the *n*-fastest no-signal trials or the left, fast part of the no-signal curve, used to estimate the SSRT. A large discrepancy between observed and predicted RT was usually taken as an index of poor fit of the horse-race model (De Jong, Coles, Logan, & Gratton, 1990; Jennings et al., 1992). However, Band and colleagues (2003) demonstrated that observed RT-predicted RT should not be used as an index of fit since they found that the discrepancy was primarily affected by variability in primary task RT and stop signal task RT.

RESULTS

CRT and error data were subjected to a within-participant trimming procedure. Mean CRTs of correct trials and error percentages were calculated after removal of outlying CRTs; i.e., CRTs longer than 2.5 standard deviations above the mean were discarded from data analysis. This resulted in a data reduction of 2.3%. All reported analyses are repeated measures ANOVAs. We tested for sphericity, and since the sphericity assumptions were satisfied we did not use any correction (most critical p -value = 0.07). First, we report the results obtained on the no-signal trials in both parts (with and without stop signals). Next, we report the analysis of the signal trials.

No-signal trials

The CRTs and error percentages of no-signal trials in the block with and without stop signals are presented in Table 2.1. We conducted a 2×3 repeated measures ANOVA, with part and flankers as within-subjects variables. As can be seen in Table 2.1, the stop signal generally slowed down the responses, $F(1, 28) = 18.99, p < 0.001$. The analysis yielded a main effect of

flanker type, $F(2,56) = 294.80$, $p < 0.001$. There was no interaction between both main effects, $F(2,56) = 1.52$, $p = 0.23$. Planned comparisons were conducted for both parts separately. In the part with stop signals, all conditions differed from each other. CRTs of trials with congruent flankers were faster than trials with NRS incongruent flankers and than trials with RS incongruent flankers, $F(1,28) = 72.08$, $p < 0.001$ and $F(1,28) = 233.32$, $p < 0.001$, respectively. There was also an effect of response set; i.e., NRS incongruent trials were faster than RS incongruent trials, $F(1,28) = 59.48$, $p < 0.001$. We found the same results for the part without stop signals. Participants responded faster on trials with congruent flankers than on trials with NRS incongruent flankers, $F(1,28) = 83.73$, $p < 0.001$, and RS incongruent flankers, $F(1,28) = 367.16$, $p < 0.001$. The effect of response set was also significant, $F(1,28) = 170.04$, $p < 0.001$.

A similar set of analysis was conducted for error percentages. The error analysis showed that participants made more errors in the part without stop signals, $F(1,28) = 26.54$, $p < 0.001$ (7.1% vs. 4.3%). Further, there was a main effect of condition, $F(2, 56) = 68.88$, $p < 0.001$. There was also interaction between both main effects, $F(2,56) = 8.98$, $p < 0.001$. We compared the conditions for both parts separately. In the part with stop signals, participants made less errors in the congruent condition in comparison to the NRS incongruent condition and the RS incongruent condition, $F(1,28) = 18.40$, $p < 0.01$, and $F(1,28) = 35.09$, $p < 0.001$, respectively. An effect of response set was found also, $F(1, 28) = 30.66$, $p < 0.001$. In the part without stop signals, less errors were made with congruent flankers, compared to NRS incongruent flankers, $F(1,28) = 23.16$, $p < 0.001$, and RS incongruent flankers, $F(1,28) = 117.23$, $p < 0.001$. The difference between NRS and RS incongruent trials was also significant, $F(1,28) = 63.89$, $p < 0.001$. In the parts with and without stop signals, none of the correlations between CRT effects and error effects reached significance, indicating that there was no speed accuracy trade-off.

Table 2.1: Reaction times and error percentages (SDs in parentheses) for both parts without and with the presentation of stop signals (S-S) in Experiment 1 (NRS and RS stand for not part of the response set, and part of the response set, respectively).

	Trial type					
	Congruent		Incongruent NRS		Incongruent RS	
	M	Errors	M	Errors	M	Errors
Without S-S	340 (33)	2.1 (2.1)	361 (33)	4.7 (3.6)	402 (37)	14.6 (7.2)
With S-S	380 (56)	0.8 (0.9)	404 (62)	2.7 (2.6)	437 (50)	9.4 (7.1)

Signal-trials

Stopping data are presented in Table 2.2. First of all, the tracking procedure worked very well. Probability to respond given a stop signal was 0.51 for neutral, 0.50 for NRS incongruent and 0.49 for RS incongruent trials (though very small, this effect is significant; $F(2, 56) = 4.14, p < 0.05$). SSRTs were estimated as briefly described in the method section. There was a main effect of flanker type for SSRTs, $F(2,56) = 6.35, p < 0.01$. Planned comparisons revealed a significant difference between congruent and NRS incongruent trials, $F(1,28) = 6.74, p < 0.05$. The difference between congruent and RS incongruent was also significant, $F(1,28) = 9.51, p < 0.05$. There was no effect of response set for SSRTs, $F(1, 28) = 1.83, p = 0.19$. For signal trials, not only the SSRT but also the mean CRTs of signal-respond trials were analyzed, by comparing observed vs. predicted signal-respond RTs, as described in the method section. This was done by means of 2 (Observed vs. Predicted) \times 3 (Flanker Conditions) repeated measures ANOVA. We found main effects of both variables, $F(1,28) = 186.94, p < 0.001$, and $F(2,56) = 128.40, p < 0.001$. Unlike Ridderinkhof et al. (1999), we found no interaction between both variables, $F(2,56) = 1.51, p = 0.22$.

Table 2.2: SSRTs, probabilities of responding given a stop signal, observed and predicted signal-respond RTs (SRT) in Experiment 1 (NRS and RS stand for not part of the response set, and part of the response set, respectively).

	Trial type					
	Congruent		Incongruent NRS		Incongruent RS	
	M	SD	M	SD	M	SD
Stop signal RT	175	46	186	46	193	41
Response ratio (%)	50.7	3.1	49.9	3.4	49.2	2.4
SRT observed	370	39	386	46	414	45
SRT predicted	328	35	348	39	370	39

DISCUSSION

With a modified flanker task, we replicated and extended the compatibility effect, observed by Kramer et al. (1994) and Ridderinkhof et al. (1999), for both CRTs and SSRTs. Analysis of CRTs of no-signal trials revealed clear effects of congruence and response set (all planned comparisons were significant). A similar pattern was found for error percentages. Next, like Ridderinkhof et al. (1999) and Kramer et al. (1994), we found that stopping was slowed down when flankers were incongruent. The differences between SSRTs of congruent and both types of incongruent trials were significant but there was no additional effect of response set. These results suggest that distracting information influences the stopping of behaviour and that being part of the response set is less important.

Another possible explanation for the difference between congruent and NRS incongruent, is the orthogonal stimulus-response compatibility effect. According to this effect an overall advantage for the up-right/down-left mapping is found (see Cho & Proctor, 2003). Applied to the present findings this would mean that the NRS flanker arrows are associated with left (pointing down) or right (pointing up). These flankers would not be NRS incongruent, but would be just a mix of congruent and RS incongruent

flankers which could explain why we found a CRT difference. This hypothesis was tested in an extra analysis on CRTs of NRS incongruent trials. In a 2 x 2 repeated measures ANOVA an interaction of the target direction (left-right) and the flanker direction (up-down) would be expected. We found a main effect of target direction. Right was processed 22 ms faster than left [$F(1,28) = 29.4, p < 0.001$]. This is not surprising since all the participants were right-handed. But more importantly, the flanker direction (up or down) did not interact with the effect of target direction ($F < 1$). This suggests that the effect of NRS incongruent flankers is not modulated by an association up-right/down-left. This analysis confirms that the effect of categorically related incongruent NRS flankers is not response related.

However, Experiment 1 does not allow us to discriminate between a possible perceptual conflict and a categorically related conflict, since our baseline condition was one with congruent flankers. There is evidence from electrophysiological studies that generally, a part of the distractor effect is due to a perceptual conflict (e.g., Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). Therefore, it is possible that the influence of incongruent NRS flankers is due to a perceptual conflict and not due to the categorical information of the flankers. In the second experiment, we will go more deeply into it and further investigate the possible effect of categorically related information, while minimizing the importance of perceptual conflicts.

EXPERIMENT 2

In the second experiment, we wanted to further investigate the findings of Experiment 1 with another task that is assumed to require inhibition: The Stroop task (Stroop, 1935). Nowadays, there are many versions of the Stroop task. It is beyond the scope of this article to discuss them all (but see MacLeod, 1991, for an extensive review of more than 50 years Stroop task). In the standard Stroop Color-Word Test, participants have to name the colors of incompatible color words (e.g., BLUE written in green; the correct answer is green) and neutral words (e.g., STAGE written in green) or repeating letter strings. Naming the color of incongruent words is

consistently slower, apparently due to the fact that the printed word is automatically processed, causing interference.

Models of the Stroop effect (e.g., the information accumulating model of Logan, 1980; Logan & Zbrodoff, 1979; and the parallel distributed-processing model of Cohen, Dunbar, & McClelland, 1990), explain these findings in terms of response nodes, whereas on congruent trials both the color and the color word activate the same response node. On incongruent trials, the color and the color word activate different response nodes, causing interference. For example, in the model of Logan and Zbrodoff (1979), activation of the word in the color naming task happens via an automatic connection, representing the automatic reading tendency in the Stroop task. This connection is also stronger than the connection between colors and responses. This difference between the strength of connections could explain why an asymmetrical incongruence effect is found (i.e., the color of the word has no effect in a word reading task, even with color words). Similar to the models in the flanker task, the fact that two responses are activated is stressed. However, just as in the flanker task, there are effects of words that are not in the response set. Klein (1964) demonstrated that the semantic meaning of a word influenced the interference effect. The more meaningful the word, the more interference it caused. Color words of the response set caused the most interference. But importantly, color words that are not in the response set also cause interference. Even semantically associated words (e.g., GRASS) may cause interference. These findings suggest that also in the Stroop task the incongruence can be manipulated and the more the words are semantically or categorically related to the color, the more interference they cause.

In the present experiment, we opted for a manual version of the Stroop task. The common finding with manual versions of the Stroop task is that the typical interference effect is still present although smaller with manual responses compared to the standard vocal responses (e.g., MacLeod, 1991; Virzi & Egeth, 1985). Sharma and McKenna (1998) further investigated the differences between the manual and vocal response and looked among other effects for the influence of response mode on the effect of response set. They found a semantic categorically related effect of color words that are not in

the response set, independent of the response mode.⁶ Color words that are part of the response set caused the most interference. In this experiment we used three types of the words: Neutral words, color words not in the response set, and color words in the response set. Participants had to react to the color of the written words, unless a stop signal was presented.

METHOD

Participants

Twenty first-year psychology students (10 females and 10 males) of Ghent University (Belgium) participated for course requirements and credit. None of them participated in the first experiment. All participants had normal or corrected-to-normal vision, were right-handed, and all were naive as to the purpose of the experiment. One participant was excluded from further data-analysis because of an error percentage of 28% (more than 3 standard deviations above the group mean).

Apparatus and signals

Apparatus and signals were the same as in the first experiment of the present study. Only the changes in comparison with the first experiment will be described. There were four ink colors (i.e., the response set: Red, yellow, green and blue) and three types of words: (a) incongruent Dutch color words from the response set (the RS color words 'rood', 'geel', 'groen', and 'blauw', meaning red, yellow, green and blue respectively); (b) incongruent Dutch color words, different from those of the response set (the NRS color words 'zwart', 'paars', 'oker', and 'bruin', meaning black, purple, ochre and

⁶ Sharma and McKenna (1998) found a marginally significant difference between color words not in response set and neutral words when the response mode was manual. However, Brown and Besner (2001) reanalyzed the data of Sharma and McKenna. Unlike the original analysis, Brown and Besner did find a significant effect of color words that were not in the response set for the manual response mode, using Bonferroni instead of Tucker HSD.

brown respectively); (c) neutral words, matched with RS color words for word frequency and word length (the abstract Dutch words 'doel', 'norm', 'niets', and 'stand', meaning goal, standard, nothing, and posture respectively). The words were presented at the centre of the screen on a black background, in the gap of an interrupted central vertical white line. This line served as fixation sign and appeared 500 ms before stimulus onset. The maximum visual angle subtended by the words was approximately $2.30^\circ \times 0.60^\circ$ (2.30° with fixation lines). The words were presented during 750 ms and required a response within 1,500 ms after onset. The next word was presented 1,500 ms after the response on the previous word. Responses were collected with a response box connected to the game port of the PC. The four black buttons of the box were labeled with one of the four color words written in black ink. All participants placed their index and middle fingers from their left- and right hand on one of the buttons.

Tasks, procedure and stop latency estimation

With the exception of the stimuli, nothing changed in comparison with Experiment 1. The presentation of the three types of words was mixed and with equal probability. The order of the words was randomized with the restriction that no color was the same as the ignored word of the preceding trial (e.g., a word written in red when the preceding trial was 'rood' written in blue) and that no response or word type appeared more than three times in a row. This resulted in 2 experimental blocks without stop signal of 98 trials and 6 experimental blocks with stop signals, also with 98 trials each. Probability of stop signal was 25% (48 stop trials for each word type). Stop latency was estimated according to the same procedures.

RESULTS

CRT and error data were subjected to the same within-participant trimming procedure as in Experiment 1. This resulted in a data reduction of 2.3%. The analyses were also the same as in Experiment 1.

No-signal trials

Results of no-signal trials of both parts with and without stop signals are presented in Table 2.3. We conducted a 2 (stop signal) \times 3 (word type) repeated measures ANOVA. As can be seen in Table 2.3 and as commonly observed, introducing the stop signal, slightly slowed the CRTs; mean CRTs for both parts are 554 vs. 588 ms, $F(1,18) = 6.35$, $p < 0.05$. We found a main effect of word type, $F(2,36) = 17.31$, $p < 0.001$. The interaction between stop signal and word type was not significant ($F < 1$), indicating that the Stroop effect was not influenced by the occasional presentation of stop signals.

Table 2.3: Reaction times and error percentages (SDs in parentheses) for both parts without and with the presentation of stop signals (S-S) in Experiment 2 (NRS and RS stand for not part of the response set, and part of the response set, respectively).

	Trial type					
	Neutral		Incongruent NRS		Incongruent RS	
	CRT	Errors	CRT	Errors	CRT	Errors
Without S-S	540 (56)	10.5 (5.3)	553 (75)	9.3 (5.0)	568 (86)	10.3 (4.7)
With S-S	569 (68)	9.1 (5.4)	588 (71)	9.1 (5.1)	607 (78)	8.6 (5.5)

Planned comparisons were conducted for both parts separately. For the part with stop signals, planned comparisons revealed that CRTs for colors of neutral words were faster than CRTs of NRS color words, $F(1,18) = 14.76$, $p < 0.01$, and CRTs of RS color words, $F(1,18) = 26.90$, $p < 0.001$. There was also an effect of response set: NRS and RS color words differed significantly from each other, $F(1,18) = 18.22$, $p < 0.001$. The same results were found for the part without stop signals. CRTs for neutral words were lower than the CRTs for NRS color words and CRTs of RS color words, $F(1,18) = 3.89$, $p = 0.06$, and $F(1,18) = 9.21$, $p < 0.01$, respectively. The effect of response set in this part was significant, $F(1,18) = 4.83$, $p < 0.05$. Unlike the CRT analyses, the error analyses revealed no differences at all (all F s are smaller than 1.19),

indicating that there was no speed-accuracy trade-off. This was confirmed by further analysis. None of the correlations between CRT effects and error effects was significant.

Signal-trials

The staircase tracking procedure worked very well in the present experiment. The probability of responding given a stop signal approximated 0.50 (0.49, 0.48 and 0.49; $F < 1$). Stopping data are presented in Table 2.4. Analysis of the signal trials showed a significant main effect of word type on SSRTs, $F(2,36) = 3.78$, $p < 0.05$. The difference between SSRT of neutral trials and SSRT of NRS color words was marginally significant, $F(1,18) = 3.47$, $p = 0.07$. The difference between neutral words and RS color words was significant, $F(1,18) = 6.86$, $p < 0.05$. Finally, there was no effect of response set ($F < 1$). Besides SSRT data, we also analyzed CRTs for signal-respond trials. Analysis showed main effects of predicted vs. observed RTs (means: 470 vs. 522 ms respectively), $F(1, 18) = 46.91$, $p < 0.001$, and of word type, $F(2,36) = 5.97$, $p < 0.01$. Like in the first experiment, we found no interaction ($F < 1$).

Table 2.4: SSRTs, probabilities of responding given a stop signal, observed and predicted signal-respond RTs (SRT) in Experiment 2 (NRS and RS stand for not part of the response set, and part of the response set, respectively).

	Trial type					
	Neutral		Incongruent NRS		Incongruent RS	
	M	SD	M	SD	M	SD
Stop signal RT	223	99	239	103	245	102
Response ratio (%)	49.1	2.9	48.0	3.0	48.8	3.2
SRT observed	511	48	523	63	533	67
SRT predicted	462	49	469	48	479	58

DISCUSSION

In this experiment, we found results that are analogous to the results of the first experiment of the present study, even though in both experiments different inhibitory tasks are used. In general, the results of this experiment also replicate and extend on the findings of Klein (1964) and Sharma and McKenna (1998). Firstly, for no-signal trials we found the traditional difference between neutral words and incongruent RS words. Furthermore, there was also an effect of response set, although in the part without stop signals it was only marginally significant. That does not alter the fact that we replicated the Stroop effect with a manual version of this task. Like other studies using a manual version of the Stroop task, the effect was rather small, but statistically reliable (see MacLeod, 1991, for a review). Secondly, we found that stopping in the stop signal task is influenced by distracting information of the Stroop task. These findings are quite similar to those of Kramer et al. (1994) and Ridderinkhof et al. (1999) with the flanker task. As in Experiment 1, SSRTs were not influenced by word type the same way CRTs were influenced. We found that stopping was easier for neutral words than for other words. However, in contrast to CRTs no difference between SSRTs of both types of incongruent words was found. Since we used in this experiment a neutral baseline condition where the degree of perceptual conflict is similar for all three conditions, the findings of this experiment cannot be related to perceptual factors. These findings suggest that categorically related distracting information suffices to cause more difficulties in the stopping of behaviour.

GENERAL DISCUSSION

In this study, we investigated the relation between different forms of inhibition. We combined the stop signal task with a slightly modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974) in the first experiment and with a manual version of the Stroop task (e.g., Sharma & McKenna, 1998) in the second experiment. In both experiments we observed

the expected congruency effects for no-signal trials in both the part with and the part without the occasional presentation of stop signals.

Moreover, the results of the experiments suggest that behavioural inhibition in the stop signal task interacts with interference control in the Eriksen flanker task and the Stroop task. These findings are a replication and extension of the studies of Kramer et al. (1994) and Ridderinkhof et al. (1999). In the latter studies, the flanker task and the stop signal task were combined and a flanker effect for SSRTs was found. The flanker task used in the present study differed however from those used in both studies mentioned. In the study of Kramer et al. (1994), neutral flankers were included besides congruent and incongruent flankers (the RS incongruent trials in our experiments). SSRTs of incongruent trials differed from SSRTs of the other types of trials, but there was no difference between the SSRTs of congruent and neutral flankers. Ridderinkhof et al. (1999), used arrows like in the present research, but only congruent and incongruent arrows (again corresponding to our RS incongruent trials) were included. In the present study NRS incongruent trials were introduced. Therefore, we could investigate whether the interaction between two inhibitory tasks, as suggested by Logan (1994) and Ridderinkhof et al. (1999), is situated at a response level since incongruent NRS distractors induce a conflict which is not situated at the response level. After all, the stop signal task requires the suppression of responses. However, the results of both experiments of the present study do not fully support the response level interpretation. Our results suggest that resolving a conflict induced by categorically related distracting information and stop signal inhibition compete for execution. An additional effect at response level cannot be fully excluded though, but the results of the second experiment seem to suggest that such an additional effect for SSRTs is not present.

In the present research, we opted for a method of investigation based on Kramer et al. (1994) and Ridderinkhof et al. (1999), introducing two inhibitory tasks that are more or less 'engrafted'. Doing so, the interaction is investigated on a trial-by-trial basis. Results of our second experiment prove the value of this technique. For instance, Pennington (1997; in Nigg, 2000) found that the Stroop task and the stop signal task did not highly correlate

and suggested that they operationalize different forms of inhibition. Nonetheless, our results suggest that a certain overlap exists. The fact that we found similar interactions in both experiments could only validate this overlap hypothesis. In light of these results, the similarity between the Stroop and flanker task is of importance. Both tasks are usually considered as measures of interference control (e.g., Nigg, 2000). The flanker task is often described as a variant of the Stroop task (e.g., MacLeod, 1991), with as most important difference that in the flanker task the competing stimulus information is spatially adjacent to the target in contrast to the Stroop where distracting information is integrated. However, we argue that there may be some other important differences, despite the fact that in both tasks congruency effects occur. The cause of the interference in the Stroop task and the flanker task differs. In the Stroop task, the more dominant reading of the word occurs faster than the naming of the ink color (MacLeod, 1991). In other words, participants have to suppress a prepotent response (i.e., the automatic reading tendency) in the Stroop task in contrast to the flanker task. That is why some authors consider the Stroop task as operationalizing inhibition of prepotent responses (e.g., Miyake et al., 2000). On this view, the interaction between the stop signal task and Stroop effect can be explained as an interaction between two forms of inhibition of prepotent responses or as an interaction between interference control and behavioural inhibition. The effect of color words that are not in the response set in the second experiment, support the second interpretation, without excluding the prepotent response hypothesis. Therefore, further research is needed here.

A major concern with respect to the present results is in the ambiguity of the concept of inhibition. Behavioural studies like the present one and the ones of Kramer et al. (1994) and Ridderinkhof et al. (1999) may help to better understand the concept of inhibition. Such results can contribute to a better definition of inhibition in general and more specifically of the different inhibitory functions. When we consider the three tasks used in the present study (i.e., stop signal task, flanker task and Stroop task), they are all examples of what is labeled 'effortful inhibition' in Nigg's taxonomy. Data from this and other studies suggest that there is an overlap between different forms of 'effortful inhibition'. In addition to the interaction of the

Stroop task and the flanker task with the stop signal task, Logan and Irwin (2000) found a similar interaction with the antisaccade task. In another line of research, Miyake et al. (2000) used the Stroop task, antisaccade task and stop signal task in a latent variable analysis to explore executive functions, and found a common underlying executive inhibitory function for these three tasks. Altogether, results from behavioural, neuropsychological and neurophysiological studies suggest a differentiation between different forms of inhibition. However, this differentiation does not imply a complete independence between different forms as indicated by the studies with the stop signal task as the present one, for instance. Further research has to explore those relations more in detail in order to model and fully understand inhibition.

THE EFFECT OF INTERFERENCE IN THE EARLY PROCESSING STAGES ON RESPONSE INHIBITION IN THE STOP SIGNAL TASK^{7,8}

In the study of this chapter, the relation between interference at the early processing stages and response inhibition was investigated. In previous studies, response stopping appeared to be slowed down when irrelevant distracting information was presented. The purpose of the present study was to further explore the relationship between interference control and response inhibition. In Experiment 1, a stop signal paradigm was combined with a global/local task. The typical global-to-local interference effect is generally attributed to early processing stages, such as stimulus perception and identification. Results of this experiment demonstrated a congruency effect for both reaction time data and stopping performance. In Experiment 2, these results were replicated with a flanker task that used stimulus incongruent but response congruent flankers. Results of both experiments suggest that response inhibition and interference at the early processing stages interact.

⁷ Verbruggen, F., Liefoghe, B., & Vandierendonck, A. (in press). The effect of interference in the early processing stages on response inhibition in the stop signal task. *Quarterly Journal of Experimental Psychology*.

⁸ We would like to thank three anonymous reviewers, Guido Band and Gordon Logan for their helpful comments on a previous version this manuscript.

INTRODUCTION

During the last few years, the relation between different kinds of inhibition and interference control has become a hot topic. Inhibition has always been a fuzzy concept, and in the past it was usually described as a unitary function. However, recently both theoretical and experimental studies pointed out that there are commonalities but also important differences between different inhibitory functions (e.g., Dempster, 1993; Nigg, 2000). An example of a theoretical study that described the relation between different inhibitory functions, is the taxonomy proposed by Nigg (Nigg, 2000). Nigg suggested that there are two main forms of inhibition: An effortful, controlled form and a more automatic form. Both kinds of inhibition are further subdivided. Examples of effortful inhibition are behavioural inhibition, defined as the suppression of prepotent or prepared responses, and interference control which prevents interference due to resource or stimulus competition (Nigg, 2000).

An empirical way of clarifying the relationship between different inhibitory functions is by combining different inhibitory paradigms. For example, Fuentes and colleagues investigated how inhibition of return (IOR) affected interference effects like the Stroop effect and the flanker effect (Vivas & Fuentes, 2001, and Fuentes, Vivas, & Humphreys, 1999, respectively). They found that IOR influenced those interference effects and suggested that inhibitory tagging in IOR affects also the processing of task-irrelevant dimensions of stimuli in the Stroop and flanker task, resulting in less distractor interference. Another method was proposed by Friedman and Miyake (2004). They used a latent variable analysis to compare different inhibitory tasks. Friedman and Miyake found that Prepotent Response Inhibition (i.e., *the ability to deliberately suppress dominant, automatic, or prepotent responses*; Friedman & Miyake, 2004, p.104) correlated with Resistance to Distractor Interference (i.e., *the ability to resist or resolve interference from information in the external environment that is irrelevant to the task*; Friedman & Miyake, 2004, p.104). On the other hand, none of these two constructs was related to Resistance to Proactive Interference (i.e., *the ability*

to resist memory intrusions from information that was previously relevant to the task but has since become irrelevant; Friedman & Miyake, 2004, p.105). Results of the above mentioned studies suggest that unlike the differences in tasks involving inhibition, these inhibitory tasks are also closely related to each other. Therefore, combining paradigms and other techniques results not only in a better understanding of the specific paradigms but tells us also something about inhibition in general.

A paradigm that is most suitable to be combined with other paradigms, is the stop signal paradigm (Logan & Cowan, 1984; Logan, 1994). In this paradigm, participants usually perform a choice reaction task. On a random selection of the trials, a stop signal instructs participants to withhold their responses. On short stop signal delays (SSD; the interval between presentation of the stimulus and the presentation of the stop signal), participants can easily suppress their responses. On the other hand, when the delay is long enough, participants will nearly always execute the response. A horse race model was proposed by Logan and Cowan (1984) to explain these results. They assume that there are two processes of which the finishing times are stochastically independent: A go process and a stop process. When the stop process finishes before the go process, the inhibition will succeed and participants will suppress their response (signal-inhibit trials). On the other hand, when the go process finishes first, participants will execute their response (signal-respond trials). The horse race model does not only describe the processes in the stop signal task, it also allows an estimation of the covert latency of stopping: The Stop Signal Reaction Time (SSRT), a measurement that has frequently proved its usefulness (see Band, van der Molen, & Logan, 2003; Logan, 1994). The usefulness of the stop signal paradigm is also evident from the widespread usage. It has already been used with different response modalities, like hand and foot movements (De Jong, Coles, & Logan, 1995), eye movements (Hanes & Carpenter, 1999; Logan & Irwin, 2000), and in different populations such as children with attention deficit and hyperactivity disorder (ADHD; e.g., Schachar & Logan, 1990; Jennings, van der Molen, Pelham, Debski, & Hoza, 1997) and younger and older adults (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Williams, Ponsse, Schachar, Logan, & Tannock, 1999).

The stop signal task has also been combined with several other paradigms that are assumed to require some kind of inhibition. Logan (1981) found no difference between inhibiting spatial compatible vs. spatial incompatible responses. Logan and Irwin (2000) replicated this null effect. However, when the participants had to make saccadic responses instead of manual responses, an interaction was found. In an antisaccade task ('look in the opposite direction'), inhibiting the antisaccadic movement appeared to be slower in comparison with the inhibition of prosaccadic movements. These authors suggested that eye and hand movements are inhibited by separate anatomical structures, causing this discrepancy. This lack of interaction with stop signal inhibition is not restricted to the inhibition of spatially incompatible responses. Verbruggen, Liefoghe, and Vandierendonck (2005) investigated the relation between negative priming and response inhibition. In a negative priming paradigm, the response to the target is delayed because the target was previously suppressed. These authors found that response stopping was not influenced by negative priming.

However, there are also studies where an interaction was actually observed between the stop signal paradigm and other inhibitory paradigms. First, Taylor and Ivanoff (2003) found that the presentation of a stop signal increased the magnitude of inhibition of return and suggested that there are components in inhibition of return that are similar to those processes used in the stop signal paradigm to suppress responses. Secondly, stopping appeared also to be influenced by distractors in tasks like the flanker task and the Stroop task. Kramer and colleagues (Kramer et al., 1994) found in a flanker task with letters that stopping was more difficult in incongruent trials compared to congruent and neutral trials. Later on, Ridderinkhof, Band and Logan (1999) replicated this finding and interpreted this finding in terms of an interaction between the suppression of incorrect responses in the flanker task and the inhibition of a motor response in the stop signal task. Logan (1994) also provided an explanation similar to the response suppression hypothesis of Ridderinkhof et al. (1999) for the data of Kramer et al. (1994).

Verbruggen, Liefoghe and Vandierendonck (2004) further investigated the response suppression hypothesis of Ridderinkhof et al. (1999). They introduced distractors that were not part of the response set. In a flanker task, similar to the one used by Ridderinkhof et al. (1999), arrows pointing up or down were the distractors that were not part of the response set, since the target arrow always pointed to the left or the right. In a manual version of the Stroop task, color words referring to other colors than the possible ink colors were used as incongruent distractors that were not part of the response set. The results of both experiments demonstrated that response stopping was also influenced by incongruent distractors that were not part of the response set. The authors concluded that being part of the response set was not the crucial factor for the interaction between congruency tasks – like the flanker task and the Stroop task – and the stop signal paradigm. In other words, the results of Verbruggen et al. (2004) suggested that the interaction between the flanker task and the stop signal task was not just an interaction between response suppression in the flanker task (i.e., the incorrect response) and response inhibition in the stop signal task (i.e., the motor response). The finding that categorically related distracting information slowed down the response inhibition suggests that interference control at different processing levels could also interact with the stop signal task. In the study of Ridderinkhof et al. (1999), interference was situated at a response stage which is a late processing stage. The use of categorically distracting information in the study of Verbruggen et al. (2004) induced a conflict at a more intermediate processing stage, concerning an abstract attribute of the stimulus (e.g., semantic category), that is different from the response stage.

In the present study, we wanted to further investigate the hypothesis that interference at processing stages other than the response stage, interacts with response inhibition. For this purpose, we will induce interference at the early processing levels, such as stimulus perception and stimulus identification. A frequently used task that is assumed to reflect interference at the early processing stages, is the global/local task (Navon, 1977). In this task, compound stimuli (usually letters) are presented and participants are asked to respond to either the global or the local pattern. An example of a

compound stimulus could be a large S (=global pattern) composed of small S's (=local pattern), as illustrated in Figure 2.2. When participants had to respond to the local pattern, responses were slowed down when the global pattern was different (= incongruent stimuli) from the local pattern (the global-to-local interference effect; Navon, 1977). However, responses to the global pattern were not influenced by the identity of the local pattern. Therefore, we will mainly focus on this global-to-local interference effect. After all, several studies that used event-related-potentials (ERPs) clearly demonstrated a primarily perceptual locus of this global-to-local interference effect (Han et al., 2003; Han, Fan, Chen, & Zhuo, 1997; Proverbio, Minniti, & Zani, 1998; Ridderinkhof & van der Molen, 1995). Based on analysis of event-related brain potentials (such as the P3 component and the lateralized readiness potential) and of the electromyogram, Ridderinkhof and van der Molen (1995) suggested that incongruent stimuli induced a perceptual conflict but no response competition (but see also Miller & Navon, 2002). Furthermore, Han et al. (2003) found that the global-to-local interference effect was mainly characterized by negative deflections over the lateral occipital-temporal cortex at 200 ms after the stimulus presentation. These findings suggest that the interference is situated at the level of stimulus perception and recognition (Han et al., 2003, p.1863).

In Experiment 1, the stop signal task was combined with the global/local task, in order to investigate the relation between response inhibition and interference control in the global/local task. The main question was whether response stopping was slowed down when the global and local patterns were incongruent. This would suggest that motor inhibition in the stop signal task is influenced by interference at the early processing stages. Another implication would be that the results of Verbruggen et al. (2004) could be generalized to yet another conflict task where the conflict is not situated at the response level.

EXPERIMENT 1

METHOD

Participants

Twenty first-year psychology students (18 females and 2 males) at Ghent University (Belgium) participated for course requirements and credit. All participants had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment.

Apparatus and signals

The experiment was run on a Toshiba notebook computer running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press). Stimuli were presented on an external 17-inch monitor, placed at a distance of 60 cm in front of the participants. The stimuli were white compound letters. There were two possible letters: 'H' and 'S' (Figure 2.2). There were two types of stimuli: Congruent (global and local shapes were the same) and Incongruent (global and local shapes were different). The global shape subtended approximately 2° of visual angle horizontally and 3° vertically. The local shapes subtended approximately 0.25° x 0.4°. The stimuli were presented in central location on a black background. In order to avoid that participants fixated at the centre of the screen to favor the processing of the local shapes, the vertical position of the global shape could vary across trials (maximum 1.5° above and below the vertical centre of the screen). Responses were collected with a response box connected to the parallel port of the notebook computer. All participants placed the index fingers of their left and right hands on the left and right buttons of the response box, respectively. Occasionally, a loud and clear auditory stop signal (750Hz, 50 dB, 50 ms) was presented through headphones shortly after the stimulus onset in the visual primary task.

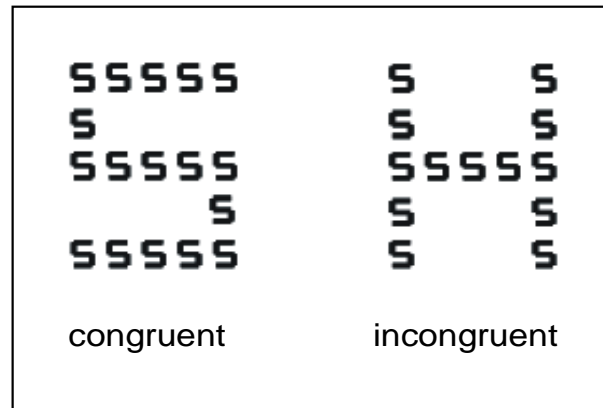


Figure 2.2: Examples of the stimuli used in Experiment 1.

Tasks and Procedure

Participants performed their task in a dimly lit, sound attenuated room. The primary task was to react to the local shape. If the target letter was an 'H', a left response was required, and the letter 'S' required a right response. Participants were instructed to respond as quickly and accurately as possible. The two types of stimuli (congruent and incongruent) occurred with equal probability and were randomized, with the restriction that no response or stimulus type appeared more than three times in a row. Each trial started with the presentation of a white fixation cross ($1.2^\circ \times 1.2^\circ$) that served as fixation point, for 500 ms. The stimuli were presented for 100 ms and required a response within 1,500 ms. The next trial was presented 1,250 ms after the response.

The experiment consisted of two parts, one with stop signals and one without. Each part started with a practice phase, followed by the experimental phase. The order of the parts was counterbalanced across participants. Participants were orally instructed and informed about the order. During the practice phase, they also received immediate feedback. The screen colored red for 100 ms when they made an error and colored orange when they responded when a stop signal was presented. In the part without stop signals, there was one practice block of 20 trials and two

experimental blocks of 120 trials. The part with stop signals consisted of one practice block of 40 trials and three experimental blocks of 120 trials. On a random selection of 30% of the trials, a stop signal was presented. This resulted in 54 stop trials for both congruent and incongruent stimuli. The stop signal delay was initially set at 250 ms and continuously adjusted according to separately staircase tracking procedures (Levitt, 1970) for each type of stimulus to obtain a probability of stopping of .50. This method provides SSRT estimations that are derived from the central part of the no-signal CRT curve and these SSRT estimates are the most reliable (Logan, Schachar, & Tannock, 1997; Band et al., 2003). Each time a participant responded to the stimulus in the presence of a stop signal, the stop signal delay decreased with 50 ms. On the other hand, when inhibition succeeded, the stop signal delay increased with 50 ms. To avoid waiting strategies, participants were informed about the tracking procedure and told that the probability of stopping would approximate .50, irrespective of whether or not they were postponing their response. At the end of each block, feedback about their performance was presented: The number of errors made during the block and the mean CRT. In the part with stop signals, the mean probability of stopping was also presented.

Stop latency estimation

SSRTs were estimated as proposed by Logan and Cowan (1984), based on the horse-race model. According to this model, after rank ordering the CRTs of no-signal trials, the left, fast part of this CRT-distribution is assumed to correspond to the distribution of CRTs of signal trials on which inhibition failed. Doing so, the finishing time of the stop process can be derived. The finishing time of the stop process corresponds to the n th CRT of the no-signal trials, where n is the result of multiplying the total number of no-signal trials by the probability of responding when a signal is presented, given a particular SSD. Since the start of the inhibition process (mean SSD) and the finishing time are known, the SSRT can be estimated. The SSRT is obtained by subtracting the start time from the finishing time or 'nth CRT minus SSD'.

RESULTS

CRT and error data were subjected to a within-participant trimming procedure. Mean CRTs of correct trials and error percentages were calculated after removal of outlying CRTs; i.e., CRTs longer than 2.5 standard deviations above the mean were discarded from data analysis. This resulted in a data reduction of 2.1%. Since we predicted a global-to-local interference effect, all post hoc tests were one-tailed t-tests.

No-signal trials

First of all, CRT data of the no-signal trials were analyzed by means of a 2 (block type: Blocks with vs. without occasional stop signal presentation) by 2 (congruency) repeated measures ANOVA. We found main effects for both factors. As can be seen in Table 2.5, participants responded faster when no signals were presented, $F(1,19) = 31.18, p < .001$. When global and local pattern were identical, responses were also faster, $F(1,19) = 11.04, p < .01$, relative to when global and local letters were incongruent. The interaction between these two main effects was not significant, $F(1,19) = 1.67, p = .21$, indicating the presentation of stop signals did not affect the global-to-local interference. One-tailed t-tests revealed a difference between congruent and incongruent trials in both conditions, $t(19) = -3.11, p < .01$, and $t(19) = -2.94, p < .01$, for the blocks with and without stop signals respectively.

Table 2.5: Reaction times and error percentages (SDs in parentheses) for both parts without and with the presentation of stop signals (S-S) in Experiment 1.

	Trial type			
	Congruent		Incongruent	
	CRT	Errors (%)	CRT	Errors (%)
Without S-S	381 (31)	3.3 (1.9)	391 (39)	4.3 (2.7)
With S-S	463 (80)	2.5 (2.4)	477 (81)	3.0 (3.0)

Secondly, error percentages were also analyzed by means of a 2 x 2 repeated measures ANOVA. The effect of condition was marginally significant, $F(1,19) = 3.82, p = .07$, indicating that participants tended to make less errors in the condition with stop signals. There was no effect of congruency, $F(1,19) = 1.87, p = .19$. The interaction was also not significant, $F(1,19) = 1.28, p = .27$.

Signal-trials

Stopping data are presented in Table 2.6. The probability of stopping came very close to the intended .50. There was no effect of congruency, $F(1,19) < 1$. The SSDs did also not differ from each other, $F(1,19) < 1$. However, the difference between SSRTs was significant, $F(1,19) = 4.65, p < .05$, indicating that stopping was 14 ms longer in incongruent trials than in congruent trials.⁹ Finally, no congruency effect was observed for signal-respond trials, $F < 1$.

Table 2.6: SSRTs, probabilities of responding given a stop signal, stop signal delay (SSD) signal-respond RTs (SRT) in Experiment 1.

	Trial type			
	Congruent		Incongruent	
	M	SD	M	SD
Stop signal RT	153	44	167	45
Response ratio (%)	50.0	3.5	50.3	2.5
SSD	304	108	303	91
SRT	435	57	431	58

⁹ Similar results were obtained using the 'mean method' for calculating the SSRT. Using this method, the SSRT is the result of the subtraction 'mean RT minus mean SSD' (see Logan & Cowan, 1984; Band et al, 2003, for a detailed description of the method). This procedure resulted in SSRTs of 158ms and 173ms for congruent and incongruent trials respectively, $F(1,19) = 4.81, p < .05$.

DISCUSSION

In this experiment, a global/local task was combined with the stop signal task in order to investigate the relation between interference in the early stages of processing on the one hand, and response inhibition on the other hand. The stop signal task was already shown to interact with congruency tasks like the flanker task and the Stroop task, where the interference was most likely situated at intermediate and late processing stages (Ridderinkhof et al., 1999; Verbruggen et al., 2004). The purpose of the present study was to further generalize these findings to interference control at the early processing stages. If interference control at these stages interacts with the stop signal task, then response stopping should be prolonged in incongruent trials in comparison with congruent trials in the global/local task.

The results of Experiment 1 are twofold. First, the analysis of CRT data of no-signal trials showed a small but significant global-to-local interference effect, indicating that participants responded faster when the global and local patterns were identical. Moreover, the global-to-local interference effect was not influenced by the occasional presentation of stop signal trials. As previously observed, participants did respond faster in the part without stop signals (Logan, 1994), but this had no effect on the global-to-local interference effect since no interaction between presentation of signals and interference effect was found.

Secondly, the probability of stopping and stop signal delay were not influenced by the identity of the global pattern, and the global-to-local interference was not significant either. The latter finding contrasts with the finding in the no-signal data. Maybe, this is due to the fact that the signal-respond data correspond to the faster trials, resulting in comparatively speaking smaller interference effects. Moreover, the effects found in the present experiment are generally quite small and therefore possibly not strong enough to emerge in a stop condition. However –and most importantly– a global-to-local interference effect was found for SSRTs. Response stopping appeared to be more difficult when the stimulus was

incongruent. This prolongation of SSRTs demonstrates that response inhibition interacts with interference control situated at the early processing stages. Therefore, the results of Experiment 1 seem to extend the findings of previous studies that combined interference tasks with the stop signal task.

However, contrary to Ridderinkhof et al. (1995) who found no response competition in the global-local task, Miller and Navon (2002) found that global shapes activated responses on no-go trials and suggested that part of the congruency effect is due to response processes. Therefore, although findings of Ridderinkhof et al. (1995) and Han et al. (2003) suggest that the interference is mostly situated at the level of stimulus perception and identification, it cannot fully be excluded that an additional response competition contributed to the interaction found in Experiment 1.

EXPERIMENT 2

In Experiment 1, we found that stopping in incongruent trials was slower than in congruent trials. In Experiment 2, the hypothesis that stopping is influenced by interference in the early processes will be further investigated with a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). Most of the studies that used a flanker task situated the congruency effect at the response-selection stage. This is also the case in models proposed to explain the flanker effect. For example, in the dual-route model proposed by Ridderinkhof (Ridderinkhof, 1997; Ridderinkhof, van der Molen, & Bashore, 1995), both distractor and target are processed: The distractor via an automatic route and the target via a controlled route. In case of an incongruent flanker, a mismatch arises between the response associated with the target and the response associated with the distractor. This response conflict needs to be resolved and delays responding (Ridderinkhof, 1997).

However, there is also evidence from both behavioural (e.g., Eriksen & Eriksen, 1979; Cohen & Shoup, 1997) and neurophysiological (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985) studies that under certain conditions at least part of the flanker effect is due to a conflict in at the level

of stimulus identification, which is an early processing stage compared to the response stage. For example, Cohen and Shoup (1997) used colored lines as stimuli and they found in their Experiment 3 that the congruency effect tended to be larger when the congruent stimuli were identical to the target in comparison with stimuli that were physically dissimilar but that belonged to the same response set. In view of the absence of a conflict at a response stage since both stimuli were associated with the same response, this effect is assumed to be situated at a more early processing level. However, in other studies that used more complex stimuli, such as letters, a difference was not always found between identical flankers and physically dissimilar but response congruent flankers (for example, Flowers, 1990). This suggests that the nature of the stimuli may be of utmost importance to find differences due to perceptual conflict at the early processing levels (Cohen & Shoup, 1997).

In order to investigate whether such a conflict in the flanker task influences the inhibition of responses, we used stimuli similar to those used in the study of Cohen and Shoup (1997). The crucial question now is whether stopping is more difficult when target and flankers are physically dissimilar but response congruent, which can be expected based on the results of Experiment 1.

METHOD

Participants

Twenty-one paid volunteers participated in this experiment (15 females and 6 males; ranging in age from 18-48 years). None of the participants participated in Experiment 1. All participants had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment. One participant was replaced due to negative SSRTs.

Apparatus and signals

Apparatus was the same as in Experiment 1. Only the changes in signals in comparison with Experiment 1 will be discussed. The stimuli were three colored parallel lines (see Figure 2.3). There were four colors: Red (RGB: 255, 0, 0), yellow (RGB: 255, 255, 153), orange (RGB: 255, 153, 0), and green (RGB: 153, 204, 0). Participants had to respond to the color of the middle line. Red and yellow were mapped on the left hand, orange and green on the right hand. This resulted in three stimulus types: Congruent (flankers and target were identical), Stimulus Incongruent (flankers and target are physically dissimilar but mapped on the same response; for example yellow flankers and a red target) and Response Incongruent (flankers and target are mapped on different responses). The total visual angle subtended by the three lines was approximately 1° by 1° . In order to avoid focusing strategies, the orientation of the lines within one trial was always the same, but was randomly varied across trials. The colored lines were presented at central location on a black background in a rectangle ($2^\circ \times 2^\circ$). The rectangle served as a fixation area and remained on the screen during the blocks.

Task, procedure and stop latency estimation

With exception of the stimuli, there were no major changes in comparison to Experiment 1. The presentation of the three types of stimuli was as in Experiment 1 pseudo-randomly mixed. The stimuli remained on screen until a response was given with a maximal RT of 1,500 ms. The next stimulus was presented 1,250 ms after the response of the previous trial. There were two parts: A part without stop signals, with a practice phase of 30 trials and two experimental blocks of 120 trials, and a part with stop signals, with a practice phase of 60 trials and five experimental blocks of 120 trials. Probability of the stop signal was 30% (60 stop trials for each stimulus type). Stop latency was estimated according to the same procedures.

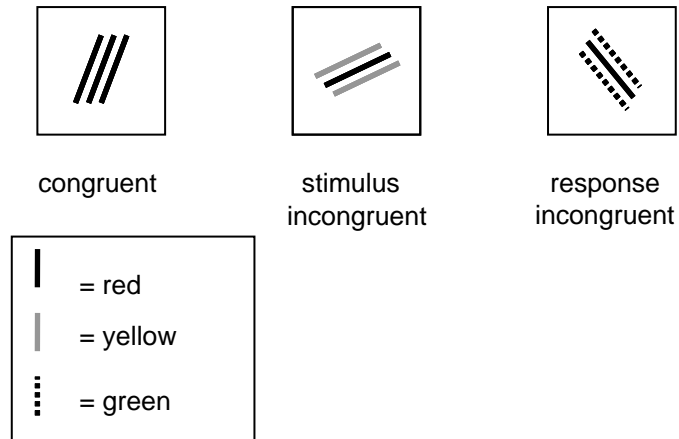


Figure 2.3: Examples of the three types of stimuli used in Experiment 2.

RESULTS

CRT and error data were subjected to the same trimming procedure as in Experiment 1. This resulted in a data loss of 2.8%. All analyses were repeated measures ANOVAs (lowest p -value of the sphericity test was .10).

No-signal trials

CRT and error data of the no-signal trials are presented in Table 2.7. A 2 (block type: Blocks with vs. without occasional presentation of stop signals) \times 3 (flankers: Congruent, stimulus incongruent, response incongruent) repeated measures ANOVA revealed a main effect for flanker type, $F(2,40) = 54.30$, $p < .001$. The difference between the two parts with and without stop signal was not significant, $F(1,20) = 1.85$, $p < .18$. The interaction was also not significant, $F(2,40) < 1$, indicating that the occasional presentation of stop signals did not influence the flanker effect. One-tailed t -tests were performed on the means of the part with and the part without stop signals. Congruent flankers resulted in faster responses (619 ms) in comparison with stimulus

incongruent (647 ms) and response incongruent flankers (668 ms), $t(20) = -5.88$, $p < .001$ and $t(20) = -11.23$, $p < .001$ respectively. The difference between these two types of incongruent flankers was also significant, $t(20) = -4.21$, $p < .001$. Analyses of the error data revealed a main effect of trial type, $F(2,40) = 7.25$, $p < .01$. There was no difference between the two parts, $F(1,20) = 1.99$, $p > .17$, and the interaction was also not significant, $F < 1$. No further analyses were performed.

Table 2.7: Reaction times and error percentages (SDs in parentheses) for both parts without and with the presentation of stop signals (S-S) in Experiment 2.

	Trial type					
	Congruent		Stimulus incongruent		Response incongruent	
	CRT	Errors	CRT	Errors	CRT	Errors
Without S-S	607 (75)	6.2 (4.3)	633 (84)	6.4 (4.8)	657 (69)	7.9 (4.7)
With S-S	630 (61)	4.3 (2.7)	660 (65)	5.2 (4.0)	680 (69)	6.7 (4.0)

Signal-trials

Stopping data are presented in Table 2.8. The probability of responding approximated .50. There was no effect of congruency, $F(2,40) = 1.22$, $p = .30$. On the other hand, the differences between flanker types for both SSDs and SSRTs were significant, $F(2,40) = 8.11$, $p < .01$, and $F(2,40) = 5.5$, $p < .01$ respectively.¹⁰ Post-hoc t-tests for SSRTs indicated that response stopping for both stimulus incongruent, $t(20) = -2.16$, $p < .05$, and response incongruent trials, $t(20) = -3.75$, $p < .001$, was prolonged in comparison to identical trials. The difference between stimulus incongruent and response incongruent trials was not significant, $t(20) = -0.70$, $p > .50$. Finally, there was also a congruency effect for signal-respond trials, $F(2,40) = 15.55$, $p < .001$.

¹⁰ As in Experiment 1, using the 'mean method' yielded similar results. The SSRTs were 169ms, 185ms and 190ms for respectively congruent, stimulus incongruent and response incongruent trials, $F(2,40) = 2.73$, $p = .07$.

Congruent trials were faster than both stimulus incongruent, $t(20) = -1.81$, $p < .05$, and response incongruent trials, $t(20) = -5.02$, $p < .001$. The difference between both types of incongruent trials was also significant, $t(20) = -3.61$, $p < .01$.

Table 2.8: SSRTs, probabilities of responding given a stop signal, stop signal delay (SSD) and observed signal-respond RTs (SRT) in Experiment 2.

	Trial type					
	Congruent		Stimulus incongruent		Response incongruent	
	M	SD	M	SD	M	SD
Stop signal RT	144	45	167	49	172	43
Response ratio (%)	50.2	3.4	49.7	3.2	49.4	2.9
SSD	461	75	475	83	490	82
SRT	569	54	584	56	622	55

In sum, in Experiment 2, the results of Experiment 1 are replicated. Like in the study of Cohen and Shoup (1997), responses to stimulus incongruent trials were slower in comparison to stimuli where the flankers were congruent. Besides this effect of stimulus congruency, there was also an additional effect of response congruency, most likely situated at a late processing stage, and which is indicated by the finding that responses to the response incongruent stimuli were the slowest. The stop signal data yielded a similar pattern. The probability of stopping was not influenced by congruency. On the other hand, main effects were found for both SSDs and SSRTs. A post hoc t-test revealed that response stopping was more difficult when the flankers were different but mapped on the same response to the target. An additional effect of response congruency on response inhibition (i.e., response incongruent trials are to some extent also stimulus incongruent trials) cannot be excluded, but the post-hoc test between SSRTs of stimulus incongruent and response incongruent trials did not reach significance.

GENERAL DISCUSSION

In the present study, the relationship between response inhibition, as operationalized in the stop signal paradigm, and interference in the early processing stages in a global/local task and a flanker task, was investigated. Results of both experiments suggest that response stopping is prolonged when irrelevant stimuli are presented.

Ridderinkhof et al. (1999) found that when they combined the stop signal task with a flanker task, response stopping on incongruent stimuli was more difficult in comparison to congruent stimuli. From this finding, the authors concluded that the suppression of incorrect responses in the flanker task and the inhibition of motor responses in the stop signal task interacted. According to Ridderinkhof et al. (1999), this suggested that in both tasks a common inhibitory mechanism was present, or, alternatively, that two separate response suppression mechanisms compete for the same resources. In other words, they argued that although the loci of the inhibitory functions may be different, resolving the conflict in the flanker task and the suppression the motor response in the stop signal task are not functionally independent from each other. Furthermore, Ridderinkhof et al. (1999) argued that these results were in line with a prefrontal executive mechanism that supports different inhibitory processes, resulting in adaptive and controlled behaviour.

In a follow-up study, Verbruggen et al. (2004) investigated whether there was still an interaction when the interference was situated at other processing stages than the response stage. For this purpose, these authors introduced distractors that were categorically related to the targets but that were not part of the response set in both a flanker task and a Stroop task. They found that with this type of distractors, response stopping was also more difficult in comparison to the congruent stimuli in the flanker task and the neutral stimuli in the Stroop task. These authors concluded that categorically related distracting information, causing interference at a probably more intermediate processing stage concerning abstract attributes of the stimulus, was sufficient to cause an interaction with the stop signal

paradigm. Therefore, the interaction between interference control and response inhibition does not necessarily have to be situated at the response level (Verbruggen et al., 2004).

The results of the present study offer further support for the hypothesis that the activation of incorrect responses in congruency tasks is not necessary to influence the stop performance. In Experiment 1 a global/local task is combined with the stop signal paradigm. In addition to the typical global-to-local interference effects for CRT data, response stopping, as indicated by longer SSRTs, was also more difficult on incongruent stimuli. This suggests that response inhibition is influenced by interference at an early level of processing. This finding was replicated in Experiment 2. In this experiment, participants performed a flanker task. The crucial comparison was the difference between congruent flankers and stimulus incongruent flankers that evoke the same response as the target. The difference between those two conditions involves a conflict in an early processing stage (similar to the global-to-local interference of Experiment 1), and an absence of a response conflict because both targets and distractors are associated with the same response. As predicted, response stopping was influenced by such a conflict in the flanker task. Taken together, the results of both experiments of the present study suggest that response stopping is influenced by interference in the early processing stages. Hence, the present study is in the first place an extension of the study of Ridderinkhof et al. (1999) and Verbruggen et al. (2004) where also an interaction between interference control in congruency tasks and response inhibition is found.

The results of the present study shed a new light on the relationship between congruency tasks and the stop signal task. All three types of congruency tasks that were shown to influence the stop performance in both the present study and previous ones (i.e., the flanker task, a manual version of the Stroop task and the global/local task), have in common that irrelevant aspects of the stimulus affect the performance on the relevant aspects (stimulus-stimulus congruency or S-S congruency; Kornblum, Hasbroucq, & Osman, 1990). Although there are some differences between these tasks, they all appear to influence stop performance in a similar way. When there are irrelevant stimulus features that are incongruent with the relevant

stimulus features, stopping is slowed down. These findings of both experiments demonstrate that interference control and response inhibition interact, and therefore, that these inhibitory processes are not functionally independent from each other. Based on the additive factors logic (Sternberg, 1969), this could also suggest that there may be a common inhibitory mechanism in both tasks. Moreover, it seems that the interaction does not necessarily have to be situated in a late stage of response production or any other response related process. Results of the present study and the study by Verbruggen et al. (2004) indicate that interference control in different stages of the stimulus-processing chain and response inhibition as operationalized in the stop signal task, interact.

Recently, several authors suggested that in congruency tasks like the flanker task, there are at least two general processes: A monitoring process and subsequently, a control process (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Ridderinkhof, 2002a). The monitoring system is assumed to detect the conflict, indicating the need for control, and engages a controller which can actually 'deal' with this conflict. For example, Ridderinkhof (2002a, 2002b), suggested that in conflict tasks where a response conflict is detected, performance can be adjusted trial-by-trial in order to deal effectively with the conflict situation. Although this account focuses primarily on trial-by-trial adjustments, there is also evidence that similar control processes occur within trials (see Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). There is also evidence from studies that used tasks similar to the ones used in the present study, that top-down mechanisms are engaged when no response conflict is present (Milham et al., 2001; Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). Within the two-process framework, interference in the early stages of processing also engages both a monitoring system and a subsequent controller. In the light of the present results, the question remains in which stage(s) the interaction with the stop signal occurs. It is possible that either the monitoring or the act of control, i.e., the suppression of the stimulus incongruent flankers, interact with the processes in the stop signal paradigm. However, the paradigm used in the present study does not allow a finer time-analysis with the purpose of investigating in which stage the interaction occurs. Moreover, it is possible

that both processes overlap in time (Ridderinkhof, Ullsperger, et al., 2004). New research may be useful here.

The results of the present study are also consistent with another conceptualization of the processing stream, namely the executive act of control model proposed by Logan and Cowan (1984). In this model, Logan and Cowan tried to integrate the concepts of motor control and cognitive control. They suggested that both motor control and cognitive control are best viewed as an interaction between an executive system that forms the intentions and keeps track of the changing goals and a subordinate system that receives the commands and actually performs the required operations. In case of the stop signal paradigm, the executive system could serve as the mechanism for response inhibition. When a stop signal is presented, the goals are changed and responses should be suppressed. This could be done by canceling the support for the processes. Since Logan and Cowan (1984) proposed that the control mechanism they suggested could operate at any point from stimulus perception to response, it seems also reasonable to assume that conflict monitoring or interference control also rely on the executive system. This implies that response stopping and interference control should compete for the same resources when they are combined. This should result in longer stop latencies for conflicting trials, which is actually observed in previous studies (Kramer et al., 1994; Ridderinkhof et al., 1999; Verbruggen et al., 2004) and the present one. Thus, a control system supporting inhibition could possibly explain the interactions between different inhibitory tasks. Note that Ridderinkhof et al. (1999) also suggested that their results were in line with the concept of a prefrontal executive system that supports interference control and response inhibition at different loci (or processing stages). Similar conclusions about common mechanisms in interference control and response inhibition were drawn by for example Friedman and Miyake (2004) and Dempster (1993). Friedman and Miyake also found in their latent variable analyses that although there are some differences in the tasks or inhibitory functions that these tasks are assumed to operationalize, they rely on similar mechanisms. Likewise, Dempster (1993) suggested that notwithstanding differences between interference

control and inhibition, they may be similar in nature, controlled by similar neuronal mechanisms.

To summarize, in the present study the relation between response inhibition and interference in the early processing stages was investigated. Both experiments demonstrated that response stopping was slowed down due to interference in early stages of processing of the primary task. This is further evidence for the hypothesis that interference control at different processing stages and response inhibition are not functionally independent, suggesting a possible common underlying mechanism in different inhibitory tasks.

STIMULUS AND RESPONSE CONFLICT-INDUCED COGNITIVE CONTROL IN THE FLANKER TASK^{11,12}

Recently, several studies investigated the top-down adjustments made after incongruent trials during conflict tasks. The present study investigated conflict-monitoring with different types of conflict. In a modified version of the flanker task, a distinction was made between stimulus-stimulus conflict and stimulus-response conflict. Six colours were mapped on three responses in order to exclude all sequences where a relevant or irrelevant stimulus- or response-related feature was repeated from trial $n-1$ to trial n . Analyses as a function of the congruency of the previous trial demonstrated that conflict adaptation was present. The stimulus congruency effect was reduced after both a stimulus incongruent trial and after a response incongruent trial. The mere response congruency effect did not vary as a function of previous congruency. These findings are discussed in relation to the distinction between conflict detection and conflict regulation.

¹¹ Verbruggen, F., Notebaert, N., Liefoghe, B., & Vandierendonck, A. (in press). Stimulus and response conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin and Review*.

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INTRODUCTION

According to the leading theories about cognitive control in conflict tasks, performance is adjusted after a conflict situation. Most studies focused on the contribution of the anterior cingulate cortex (ACC), and suggested that an evaluation device, the ACC, detects the conflict which is subsequently a signal for an adjustment in cognitive control via a regulative device: The dorsolateral prefrontal cortex. In behavioural studies concerning conflict monitoring, the research focused on the effect of congruency of the previous trial on the congruency effect in the current trial. Gratton, Coles, and Donchin (1992) demonstrated that in a flanker task, the effect of incongruent distracting flankers decreased when the previous trial was also incongruent (i.e., the so-called Gratton-effect). Later on, this finding was replicated in the flanker task (e.g., Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; see also Botvinick et al., 2001), and other conflict tasks such as the Simon task (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) and the Stroop task (Kerns et al., 2004). These authors suggested that the modulation of the congruency effect by the sequence of congruency is a behavioural consequence of conflict detection by the ACC and the subsequent adjustments in cognitive control (Gratton et al., 1992; Botvinick et al., 1999).

Until now, most studies focused on conflict-adaptation in terms of response conflict in conflict tasks. Several studies demonstrated that the ACC is only activated when a response conflict is present. Van Veen, Cohen, Botvinick, Stenger, and Carter (2001) used a flanker task with three conditions: (1) Congruent trials (CO; i.e., target and flankers were identical), (2) Stimulus Incongruent or stimulus-stimulus conflict trials (SI; i.e., target and flankers were non-identical but led to the same response), and (3) Response Incongruent or stimulus-response conflict trials (RI, target and flankers were mapped on different responses). Van Veen et al. found that, although SI trials were slower than CO trials, there was no ACC activation in SI trials. This was replicated in the Stroop task. Milham et al. (2001) found that categorically related stimuli that were not associated with a response

(i.e., colour words that were not part of the response set) did not activate the ACC. Taken together, these results suggest that the ACC is indeed only activated when a response conflict, due to the common activation of two different responses, is detected.

However, several neuroimaging studies found that certain regions that ought to be responsible for top-down modulations in case of a response conflict were also active in SI trials. For example, Milham et al. (2001) observed that the DLPC was activated in both SI and RI trials in comparison with CO trials and suggested that the DLPC was involved in attentional control, biasing the selection of information in the task-relevant processing stream. Liu, Banich, Jacobson, and Tanabe (2004) found similar results with a combined spatial Stroop/Simon task. These authors also demonstrated that the DLPC was active for both stimulus-stimulus and stimulus-response conflict. Thus, based on the conflict monitoring theory in which the DLPC is assumed to be the regulative device (Botvinick et al., 2001), it was proposed that top-down adjustments were also made after SI trials (Liu et al., 2004).

Yet, not all studies agreed with the notion of an active form of conflict adaptation in interference tasks (e.g., Hommel, Proctor & Vu, 2004; Mayr, Awh, & Laurey, 2003; Notebaert, Soetens, & Melis, 2001). Hommel et al. (2004) argued that the conflict adaptation pattern in the Simon task is due to the sequence of specific stimulus-response features, without the need for active top-down adjustments. Similarly, Mayr et al. (2003) suggested that the adaptation pattern could be due to stimulus-response repetitions since they found that the pattern was not present when only target-response changes were included in the analyses. However, Kerns et al. (2004) and Notebaert, Gevers, Verbruggen and Liefoghe (in press) demonstrated that this conflict adaptation was still present in a Stroop task, even when target and distractor repetitions were excluded. Similar results were obtained in an arrow version of the flanker task by Ullsperger, Bylsma, and Botvinick (in press). These authors found the conflict adaptation pattern after eliminating stimulus repetitions. Finally, when sequential effects of congruency are carefully balanced against repetition effects, the conflict monitoring pattern was still found (Wühr, in press). Based on these results, it seems that at least to some extent, behavioural adaptations are made after conflict situations.

In the present study, we used a flanker task with three types of stimuli (CO, SI & RI trials) with 6 stimuli mapped onto 3 responses. Since we were interested in top-down effects in the flanker task, we wanted to exclude all possible repetitions of stimulus- and response-related features. However, for certain transitions (SI-RI & RI-SI transitions) this is not possible with the often used 4-to-2 mapping. Therefore, we opted for a 6-to-3 mapping (see the Appendix for an elaboration of this issue). Our purpose was threefold. First, we wanted to replicate the conflict adaptation pattern in a flanker task by means of sequential analyses when stimulus- and response-related repetitions were excluded. Secondly, it was our purpose to find behavioural evidence for top-down conflict adaptations following stimulus-stimulus interference. The question is whether the conflict monitoring pattern is restricted to response conflict. Until now, there is no direct behavioural evidence for these adjustments and it is rather speculative that the activation of the prefrontal regions like the DLPC will actually lead to behavioural adaptations after SI trials. Thirdly, we wanted to investigate to which end conflict monitoring is specific. Is there a generalization from stimulus-stimulus conflict to stimulus-response conflict and vice-versa?

EXPERIMENT

METHOD

Participants

Twenty-six paid volunteers (10 females; mean age: 20.3 years, SD: 2.59) participated. All had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment.

Apparatus and signals

The experiment was run on a Pentium 4 PC running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press). Stimuli were presented on a 17-inch monitor placed at a distance of 60 cm in front of the participants. Participants were tested in groups of three or four. The stimuli

consisted of three coloured parallel lines. The compound stimuli were 30 x 50 pixels (width x length) large. There were six different colours: Red (RGB: 255, 0, 0), green (RGB: 0, 255, 0), blue (RGB: 0, 0, 255), orange (RGB: 255, 157, 0), yellow (RGB: 255, 255, 0), and violet (RGB: 255, 0, 255). The stimuli were presented at the centre of the screen in a grey square (60 x 60 pixels; RGB: 119, 119, 199) that remained on the screen during the whole experiment. To avoid that participants can keep focusing on one part of the display, the orientation of the stimuli within one trial was always the same but could vary across trials. Responses were collected via a QWERTY keyboard (keys 'V', 'B' and 'N') and participants had to respond with the index- middle and ring finger of their dominant hand.

Tasks and Procedure

The task was to react to the colour of the middle line and ignore the two flanking lines. We used six different colours and three different responses. Red and green targets were mapped on the index finger ('V'), blue and orange targets on middle finger (key 'B') and yellow and violet were mapped on the ring finger (key 'N'). There were the three types of stimuli: Congruent (CO), Stimulus incongruent (SI), and Response incongruent (RI). With regard to the sequence of trials, there were nine transition types ('congruency trial $n-1$ ' x 'congruency trial n ') that occurred with equal probability. This resulted in 1/3 CO trials, 1/3 SI trials and 1/3 RI trials. Trial type and responses were also crossed and for RI trials, the 4 possible distractor colours were equated. Each trial started with the presentation of a white fixation cross (10 x 10 pixels) in the centre of the screen for 500 ms. During the experimental blocks, the stimuli required a response within 1,500 ms. The next trial was presented 750 ms after the response.

Instructions were presented on the screen. Both accuracy and response speed were emphasized. The experiment started with two practice blocks of 30 trials. In the first practice block, there was no speed pressure. In the second practice block, the stimuli required a response within 1,500 ms. In both practice blocks, response mappings were presented at the top and the bottom of the screen by means of three groups of little coloured squares.

This information was no longer present during the experimental blocks. The experiment consisted of 14 blocks of 82 trials. The first trial of each block was not analyzed. This resulted in 378 trials for each type of congruency. When the congruency of the previous trial is also taken into account, there were nine transition types and 126 trials for each type of transition.

During the whole experiment, participants received immediate feedback for 200 ms during the intertrial interval. The word '*fout*' (Dutch for 'wrong') appeared when participants made an error and the words '*reageer sneller*' (Dutch for 'respond faster') were presented when they did not respond in time (this information could of course not appear during the first practice block). At the end of each block, the number of errors made during the block and the mean RT were displayed and participants were allowed to pause.

RESULTS

Only those trials where none of the stimulus-related or response-related features was repeated, are included in the data-analysis. RT data were subjected to a within-participant trimming procedure. Mean RTs of correct trials were calculated after removal of outlying RTs for each type of transition (i.e., RTs longer than 2.5 standard deviations above the mean). Also, trials that followed an error were not further analyzed. On average, this procedure resulted in a total data reduction of 59.2% [exclusion of all kinds of repetition effects resulted in a total data reduction of 53.2%, of which 12.2% was due to repetitions of response-related but not stimulus-related features; when errors and trials that were preceded by errors were excluded, there was an additional data reduction of 4.7%, and finally, the outlier analyses resulted in an extra reduction of 1.4%]. All reported F-values are approximations to Wilks' lambda.

Combined analyses

The RT-data were analyzed by means of a 3 (congruency trial $n-1$) by 3 (congruency trial n) repeated measures MANOVA. The data are presented

in Figure 2.4. Performance on trial n was influenced by the congruency of trial n itself, $F(2,18) = 55.66, p < .001$. The effect of the congruency of trial $n-1$ and the interaction between both main effects were both marginally significant, $F(2,18) = 3.25, p = .06$ and $F(4,16) = 2.80, p = .06$, respectively. This suggests that participants make top-down adjustments after incongruent trials and that these adjustments influence the congruency effect on the current trial. Error data were also analyzed by means of a 3x3 repeated measures MANOVA. Participants made slightly more errors on RI trials, compared to CO trials and SI trials. This difference did not reach significance, $F(2,18) = 2.91, p = .08$. There was also no effect of the previous trial, $F(2,18) < 1$, nor an interaction, $F(4,16) < 1$.

Table 2.9: Error percentages (SDs in parentheses) for the different types of stimuli on trial n as a function of the congruency of trial $n-1$ (congruent, CO; stimulus incongruent, SI; response incongruent, RI).

Trial n-1	Trial n		
	CO	SI	RI
CO	5.1 (2.9)	4.5 (2.4)	6.1 (5.6)
SI	4.7 (3.1)	4.5 (4.6)	5.8 (4.4)
RI	4.6 (5.1)	3.7 (3.3)	6.4 (7.8)

In the subsequent analyses of RT data, a distinction was made as a function of the type of congruency in the current trials. Different analyses were performed for the effect of stimulus-congruency (i.e., by comparing CO and SI trials), and response-congruency (i.e., by comparing SI and RI trials).

Stimulus congruency

The effects of congruency of trial n and trial $n-1$ were tested by means of a 2 (trial n : CO vs. SI) x 3 (trial $n-1$: CO vs. SI vs. RI) repeated measures MANOVA. There was no main effect of congruency on trial n , $F(1,19) < 1$. The effect of the congruency of trial $n-1$ did not reach significance, $F(2,18) = 2.68, p = .09$, but more importantly, the interaction was significant, $F(2,18)$

=4.02, $p < .05$, indicating that the stimulus congruency effect was influenced by the congruency of the previous trial. Different 2 (trial n) \times 2 (trial $n-1$) ANOVAs indicated that the stimulus congruency effect (CO-SI) depends on the congruency of the previous trial. Compared to trials that followed CO trials, the stimulus congruency effect became smaller after a SI trial, $F(1,19) = 4.12$, $p = .06$ and after a RI trial, $F(1,19) = 4.18$, $p = .05$, although both interactions were only marginally significant. Stimulus conflict and response conflict in the previous trial had the same effect on the stimulus congruency effect on the current trial, $F(1,19) < 1$. As can be seen in Figure 2.4, when the previous trial was congruent, there was a significant stimulus-congruency effect, $t(19) = -3.21$, $p < .01$. This difference between CO and SI trials disappeared after an SI trial, $t(19) < 1$ and after an RI trial, $t(19) < 1$.

Response congruency

In most studies using the flanker task, effects of response congruency are investigated by comparing CO trials with RI trials. Doing so, we clearly find a conflict adaptation pattern. The 2 (trial n : CO vs. RI) \times 3 (trial $n-1$: CO vs. SI vs. RI) interaction was significant, $F(2,18) = 5.17$, $p < .01$, indicating that the difference between CO and RI trials was smaller after incongruent trials. The response congruency effect became smaller after SI trials, $F(1,19) = 6.26$, $p < .05$, and after RI trials, $F(1,19) = 6.52$, $p < .05$. Whether the previous trial was SI or RI did not matter, $F(1,19) < 1$. However, the difference between CO and RI is a combined effect of stimulus and response conflict. The mere response conflict is the difference between SI and RI. Therefore, we performed another 2 (trial n : SI vs. RI) \times 3 (trial $n-1$: CO vs. SI vs. RI) repeated measures MANOVA. There was a main effect of congruency on trial n , $F(1,19) = 99.82$, $p < .001$, and also a main effect of the congruency of the previous trial, $F(1,18) = 5.07$, $p < .05$. Most importantly, the interaction was not significant, $F(2,18) < 1$, indicating that the mere response conflict was not influenced by the congruency of the previous trial.

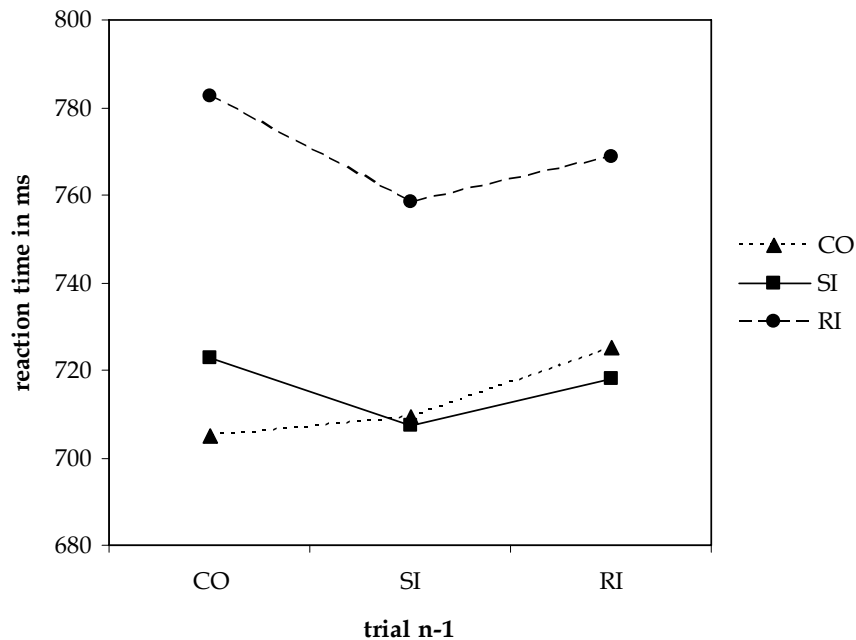


Figure 2.4: Reaction times for the different types of stimuli on trial n as a function of the congruency of trial $n-1$ (congruent, CO; stimulus incongruent, SI; response incongruent, RI).

DISCUSSION

The present study investigated whether conflict adaptations in terms of smaller congruency effects after incongruent trials can be found for complete alternations of all stimulus- and response-related features and whether these adjustments are restricted to stimulus-response conflict. Most studies focused on response conflict and results of these studies are generally twofold. First of all, neuroimaging data suggested the existence of conflict monitoring with a distinction between an evaluation device, the ACC, and a regulative device, the DLPC. When a response conflict is detected via the ACC, top-down adjustments are made. Secondly, these top-down adjustments are observed in behavioural data. After a response incongruent

trial, the response congruency effect decreases or even disappears (e.g., Gratton et al., 1992; Botvinick et al., 1999). This sequential effect is assumed to be evidence for the conflict monitoring theory.

Although the ACC is only activated when a response conflict is present, several studies demonstrated that the DLPC was also active in case of a stimulus-stimulus conflict (e.g., Milham et al., 2001; Liu et al., 2004). Based on this activation in prefrontal regions, it was hypothesized that top-down adjustments were made after a stimulus conflict, resulting in a smaller stimulus congruency effect on the next trial, similarly to the top-down adjustments made after an RI trial. In order to find direct behavioural evidence for this hypothesis, both stimulus-stimulus and stimulus-response conflict were included in the present study. Moreover, by using a 6-to-3 mapping, we were able to exclude all possible repetitions of stimulus- and response-related features, since it was argued by e.g., Mayr et al. (2003), that the conflict monitoring pattern is mainly due to stimulus-response repetitions. By excluding all kind of repetitions, this possible confound is avoided and any adaptations found in the present study are likely to be top-down adjustments. The question was whether there was an effect of the congruency of trial on the congruency effect in the current trial and whether this effect was conflict specific or not.

The results of the present study are threefold. First and most importantly, we observed the conflict adaptation pattern or the so-called Gratton-effect when all kinds of stimulus- and response related repetitions were excluded, which contradicts the results of Mayr et al. (2003). Secondly, the sequential analyses revealed conflict monitoring for stimulus congruency. After an SI trial, the stimulus congruency effect disappeared completely, providing direct behavioural evidence for conflict monitoring after SI trials. This is consistent with the finding that prefrontal regions associated with top-down adjustments after response conflict, such as the DLPC, are also activated in SI trials. Since one has always to be careful in drawing conclusions from overlapping brain areas in different tasks or different types of trials, the present study provides further evidence for the notion of cognitive control in different conflict situations.

A third finding of the present study concerns the reduction of stimulus interference after both SI and RI trials. This is actually not very surprising since RI trials are also stimulus incongruent. A bit more puzzling is the observation that the mere response conflict (SI-RI) does not change after an RI trial. When one compares RI trials with CO trials - which is typically done when conflict adaptations in the flanker task are investigated - the overall response congruency effect decreases after both SI and RI trials. But when the overall response conflict is divided into stimulus and response conflict, our data suggest that there was no extra adaptation for the mere response congruency effect after RI trials, contrary to the stimulus conflict that was absent after SI and RI trials.

This finding may seem quite odd because in previous studies response incongruent trials did lead to conflict monitoring, resulting in a smaller response congruency on the next trial (e.g., Kerns et al., 2004). However, a possible explanation is that in the present study, two different types of conflict were intermixed. This has two important consequences. First, SI trials would not benefit of adjustments made after an RI if these adjustments were made as a function of the response conflict. Secondly, in our study the probability that an RI trial is followed by another RI trial is only 1/3, whereas in other studies, this probability is usually 1/2. But the probability that an incongruent trial (SI or RI) is followed by another incongruent trial is 2/3. Therefore, it seems beneficial to make after both types of conflict the same top-down adaptations as a function of the common feature of different co-occurring types of conflict and this could explain why no difference was found between SI and RI trials. Another possibility might be that in the present study, arbitrary response mappings were used. Most of the previous studies that investigated conflict monitoring used overlearned stimulus-response mappings (e.g., responding to the direction of an arrow). By using more complex stimulus-response mappings, like in the present study, it could be the case that participants deal at a different way with the response conflict by focussing more on the stimulus processing. Future research is needed here.

This hypothesis of similar adjustments for different -but intermixed- types of conflict is in line with the proposal of Milham et al. (2001). They

argued that after the detection of a conflict, attention is drawn to the processing of task-relevant information. In a flanker task, this implies that the processing of the target should be improved. Since both stimulus and response congruency occur during - although at different stages - processing of the target, behavioural adjustments are possibly to be similar after the two types of conflict. Again, if it is the case that the same adjustments are made after SI trials and RI trials, one expects no interaction between the congruency of trial $n-1$ and the congruency of trial n when one compares SI and RI trials. Note that we do not argue it is not possible that adjustments are made as a function of response congruency in other designs. However, the data of the present study suggest that when different types of conflict are combined in a flanker task and by using an arbitrary stimulus-response mapping, this was not the case.

Thus, in the present study, we found a conflict monitoring pattern for incongruent trials. All types of stimulus- and response-related repetitions were excluded and therefore, it seems less likely that the pattern is induced by bottom-up repetition effects. Although we must keep in mind that some effects may be task-specific, we demonstrated that at least under certain conditions, top-down behavioural adjustments are made after incongruent trials, resulting in a smaller congruency effect on the next trial. Secondly, the present study demonstrates that conflict monitoring is not restricted to conflict at a response level. Although it is still not clear from neuroimaging studies which specific regions are associated with conflict detection in an SI trial, both behavioural studies, like the present one, and imaging data support the hypothesis that after a stimulus-stimulus conflict behavioural adaptations are made, resulting in an adaptation of the stimulus congruency effect. A final important observation is the fact that only the stimulus conflict is reduced whereas the mere response conflict does not decrease after incongruent trials, probably due to the co-occurrence of different types of conflict.

APPENDIX

When one wants to investigate the amount of cognitive control in the flanker task, one has to take into account that lower-level repetition effects can explain at least part of the conflict-monitoring pattern (see e.g., Mayr et al., 2003). The most obvious solution for this problem is the elimination of all possible repetitions of stimulus features. Therefore, in the present study all target, distractor and response repetitions will be excluded; the distractor of trial $n-1$ may not be the target of trial n , the target of trial $n-1$ may also not become the distractor on trial n and finally, the response associated with the distractor of trial $n-1$ may not be the response on trial n .

With regard to the effects of stimulus congruency, this will lead to some problems in a typical 4-to-2 design with 4 stimuli (e.g., L1, L2, R1, and R2) and 2 responses (e.g., Left & Right). However, in a sequential design there are two transitions that do not allow the exclusion of all kind of repetitions effects. First, after an SI trial, it is not possible to have an RI trial. For example, after the SI trial 'L1 L2 L1', all RI trials are excluded because at least one stimulus feature will be repeated ('R1 L1 R1'; 'R1 L2 R1'; 'R2 L1 R2'; 'R2 L2 R2'; 'L1 R1 L1'; 'L2 R1 L2'; 'L1 R2 L1'; 'L2 R2 L2'). The same holds for RI trials followed by SI trials.

This problem is avoided when one uses 6 stimuli (L1, L2, M1, M2, R1, and R2) and 3 responses (e.g., Left, Middle, and Right). With such a design, it is possible to have RI trials without any repetitions after an SI trial and reversely, to have SI trials after an RI trial (e.g., 'M1 R1 M1' vs. 'L1 L2 L1').

CHAPTER 3

THE INFLUENCE OF DIFFERENT TYPES OF COMPATIBILITY ON STOP SIGNAL INHIBITION

In the previous chapter, we argued that selective suppression can occur at different processing stages, dependent on the type of conflict. Moreover, we found that the selective suppression of irrelevant stimulus features at different processing stages interacts with response inhibition in the stop signal task. The implications are twofold. First, these results provide further behavioural evidence for common mechanisms in different inhibitory tasks. Secondly, we suggest that the activation-suppression hypothesis needs to be adjusted, since Ridderinkhof (Ridderinkhof, Band, & Logan, 1999; Ridderinkhof, 2002a) explicitly stressed the fact that an incorrect *response* becomes inhibited, whereas our results demonstrated that irrelevant stimulus features that are not response related can also become inhibited. However, there remains one important unsolved problem before we can accept the hypothesis that selective suppression, as conceptualized within the activation-suppression hypothesis, interferes with stop signal inhibition.

As explained before in Chapter 2, the activation-suppression hypothesis is clearly based on the dual-route model, and it assumes that an incorrect response becomes inhibited. So far, we used different interference tasks where the conflict is due to the presentation of irrelevant distractors. These tasks are often labeled as stimulus congruency tasks. But another task that is also often used in the context of the dual-route model is the Simon task (cfr. *infra* for a more detailed description of the task). This task is assumed to be an example of a stimulus-compatibility task, and the major difference with tasks like the flanker task is that there is no presentation of a distractor. On the contrary, the conflict is due to the location of the relevant stimulus, resulting in an overlap with the response set and the stimulus location.

So far we demonstrated that in stimulus congruency tasks like the flanker task, selective suppression and response inhibition interact. Of course, if the interaction is indeed due to the fact that there is an active mechanism that suppresses the irrelevant stimulus features at different

processing stages and in different conflict tasks, then we should be able to demonstrate that stopping responses should take longer in incompatible Simon trials, compared to compatible Simon trials.

In other words, where we wanted to demonstrate in Chapter 2 that the conflict did not need to be situated at a response related processing stage, we will use the reverse logic in the present chapter. By demonstrating that there is also an interaction between selective suppression of an incorrect response in stimulus-response compatibility and stop signal inhibition, we can provide further evidence for common mechanisms in different inhibitory tasks. By using the Simon task, we can also try to tackle another problem or at least another gap in the research about the relation between stop signal inhibition and other forms of inhibition. Several researchers found no effect of a *pure* stimulus-response compatibility task –in which the conflict is presumably also situated at a response stage– (cfr. *infra*) on stop signal inhibition (Logan, 1981; Logan & Irwin, 2000; van den Wildenberg & van der Molen, 2004). Given the findings with for example the flanker task, this may seem quite odd and we will try to offer an explanation for the different results.

To summarize, in next study the crucial question will be whether stimulus-response compatibility in the Simon task can have an effect on stop signal inhibition. If this is not the case, we will probably need to reject or at least re-interpret our assumption that selective suppression in conflict or interference tasks interact with stop signal inhibition.

**EFFECTS OF STIMULUS-STIMULUS COMPATIBILITY
AND STIMULUS-RESPONSE COMPATIBILITY
ON RESPONSE INHIBITION^{13,14}**

Previous studies demonstrated that interference control in stimulus-stimulus compatibility tasks slowed down stopping in the stop signal task (e.g., Kramer, Humphrey, Larish, Logan and Strayer, 1994). In the present study, the impact of stimulus-stimulus compatibility and stimulus-response compatibility on response inhibition is further investigated. In Experiment 1, the stop signal task was combined with a traditional horizontal Simon task and with a vertical variant. For both dimensions, stopping responses was prolonged in incompatible trials, but only when the previous trial was compatible. In Experiment 2, the Simon task was combined with a spatial Stroop task in order to compare the effects of stimulus-stimulus and stimulus-response compatibility. The results demonstrated that both types of compatibility influenced stopping in a similar way. These findings are in favor of the hypothesis that response inhibition in the stop signal task and interference control in conflict tasks rely on similar mechanisms.

¹³ Verbruggen, F., Liefoghe, B., Notebaert, W., & Vandierendonck, A. (in press). The effects of stimulus-stimulus compatibility and stimulus-response compatibility on response inhibition. *Acta Psychologica*.

¹⁴ We would like to thank Wery van den Wildenberg and Richard Ridderinkhof for their useful comments on a previous version of this manuscript.

INTRODUCTION

In the study of selective attention, conflict tasks have always proven to be useful instruments. In a typical conflict task, like the Stroop, flanker and Simon task, the relevant stimulus feature is accompanied with irrelevant distracting information. In general, these conflict tasks do not only show that people are capable of dealing with the interference at different stages of processing caused by the distracting information, but also that this interference is associated with a cost, as measured by reaction time (RT) differences. Numerous studies already focused on a better understanding of how this interference arises and what the consequences are for behaviour. In this introduction, we will focus on two frequently used conflict tasks: The Eriksen flanker task (Eriksen & Eriksen, 1974) and the Simon task (Craft & Simon, 1970). In a flanker task, the target stimulus (e.g., the letter 'K') is flanked by distractors (e.g., the letter 'H'). The difference between compatible and incompatible trials¹⁵ in the flanker task is generally attributed to interference at (at least) two different processing stages. First, even though physically different targets and distractors were mapped onto the same response alternative, an RT difference is often found (e.g., Eriksen & Eriksen, 1979; Verbruggen, Liefvooghe, & Vandierendonck, in press a). Secondly, besides this effect of stimulus compatibility (in the literature, this effect is called stimulus-stimulus congruency or SSC), an additional effect of response compatibility is observed. Physically different distractors that lead to a different response cause more interference compared to dissimilar flankers that are associated with the same response as the target.

Alternatively, in the Simon task, the conflict is not induced by the presentation of irrelevant distractors. In a traditional Simon task (e.g., Craft & Simon, 1970), participants have to respond to a relevant stimulus-feature (e.g., the color or the shape of the stimulus) and the position of the stimulus

¹⁵ For the ease of use, we will also use the terms 'compatible' and 'incompatible' (instead of congruent and incongruent) for the description of the interference effect in the flanker task.

is always irrelevant. Thus, there is an overlap between the irrelevant stimulus feature - the position of the stimulus - and the response set. When the stimulus position corresponds with the response side (e.g., left key press to a stimulus that is presented on the left of the screen), responses are typically faster compared to trials where there is a mismatch between stimulus position and response side.

These compatibility effects in the flanker task and Simon task can easily be interpreted in terms of a dual-route hypothesis (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Ridderinkhof, 1997; Ridderinkhof, van der Molen, & Bashore, 1995). Generally, in a dual-route model, the distinction is made between a direct and a controlled route. The relevant stimulus information is assumed to be processed via the controlled route, which is relatively slow since responses are assigned via an arbitrary response mapping. Irrelevant information on the other hand, is processed in a fast and automatic way via the direct route, based on existing stimulus-response links. This implies that response codes are pre-activated first via the direct route. When this response code corresponds to the required response (i.e., compatible trials), responses to the stimulus will be faster compared to trials where a different response code is pre-activated.

For example, for an arrow version of the flanker task, it is assumed that the relevant target arrow is processed via a controlled route and activates the response according to the mapping rule (Ridderinkhof et al., 1995). Via an automatic route, the flanking arrows activate a second response. In case of incompatible flankers, this second response will be different from the response to the target. In other words, there will be a conflict between those two responses at the response-production stage. This response conflict needs to be resolved and delays responding. The same principle holds for the stimulus-response compatibility (SRC) effect in the Simon task. The relevant stimulus feature (e.g., color of the stimulus) in the Simon task is processed via a controlled route and activates the correct response. Via the automatic route, a second response code is activated, due to the position of the stimulus. Again, this pre-activation of a response code will lead to faster responses in case of compatible trials, compared to incompatible trials. Thus, in both tasks, there is a conflict due to the activation of incorrect responses.

This conflict needs to be resolved and Ridderinkhof (2002) proposed the activation-suppression hypothesis, suggesting that the automatic activation of the incorrect response is selectively suppressed by a central inhibitory mechanism. Whereas the irrelevant response code is the result of an automatic activation, the suppression of this response is assumed to be an externally imposed active process. This active process takes time and this can explain why participants respond slower on incompatible trials. Ridderinkhof (2002) found support for this suppression mechanism in the observation that the Simon effect was strongest for fast responses. He assumed that these responses occurred before the suppression occurred.

Besides models and studies that focused on the in-depth investigation of separate conflict tasks, other studies combined inhibitory paradigms in order to understand interference (e.g., Hommel, 1997; Vivas & Fuentes, 2001). The idea is that interactions between tasks that are assumed to reflect some kind of inhibition or interference control, could tell us something more about the processes in different tasks. In line with this kind of studies, in the present study we investigate the relation between interference control in different congruency tasks on the one hand, and stopping responses on the other hand.

A widely used paradigm to investigate response inhibition is the stop signal paradigm (Lappin & Eriksen, 1966; Logan & Cowan, 1984). In its most frequent form, auditory stop signals are occasionally presented during a choice reaction time (CRT) task with visual stimuli. The stop signal informs participants that they have to withhold their response. When the stop signal is presented shortly after stimulus presentation, participants can easily suppress their response (i.e., signal-inhibit trials). Alternatively, when the stop signal is presented near the execution of the response, participants are no longer capable of withholding their response (i.e., signal-respond trials). To explain these data, a horse race model was proposed with two processes: A go process and a stop process (Logan et al., 1984). The finishing times of both processes are assumed to be stochastically independent. Based on the assumptions of the horse race model, one can estimate the latency of the covert stopping process: The stop signal reaction time (SSRT). This measurement has proven its usefulness by the widespread use of the

paradigm (for a review, see Logan, 1994). Also, simulations by Band, van der Molen and Logan (2003) showed that the SSRT can be reliably estimated under specified experimental and theoretical conditions.

Interestingly, several authors demonstrated that response inhibition in the stop signal task is influenced by interference control at different stages of processing in different versions of the Eriksen flanker task. Kramer, Humphrey, Larish, Logan, and Strayer (1994) and Ridderinkhof, Band and Logan (1999), who used the arrow version of the flanker task that was described above, found that SSRTs were longer for incompatible than for compatible trials. Whereas Kramer et al. (1994) suggested that stopping more than one response in case of an incompatible trial caused this SSRT increase, Ridderinkhof et al. (1999) attributed this delay in stopping to the interference control in the flanker task. The latter authors suggested that in case of an incompatible trial, the incorrect response should be suppressed and that this response suppression interacted with the response inhibition in the stop signal task. In other words, the active suppression mechanism, as suggested by Ridderinkhof (2002), and the stopping of responses, may rely on a common mechanism or at least common resources and for that reason they interact in behaviour (Ridderinkhof et al., 1999).

In two follow-up studies, Verbruggen, Liefvooghe and Vandierendonck (2004; in press a) investigated whether incorrect response activation was a necessary factor for the interaction between the flanker task and the stop signal task. It was demonstrated that stimulus-stimulus interference at more central processing stages in both flanker and Stroop task (i.e., interference caused by categorically related information) interacts with the stopping of responses in the stop signal task (Verbruggen et al., 2004). Moreover, interference at early processing stages in a flanker task (i.e., interference caused by a non-identical stimulus mapped on the same response) also resulted in longer SSRTs (Verbruggen et al., in press a). These findings suggest that interference control at different processing stages interacts with stopping, even without the activation of an incorrect response. In other words, the suppression of irrelevant stimulus information interacts with stopping responses, irrespective whether this irrelevant information is response related or not.

In the present paper, the interaction between compatibility tasks and the stop signal task will be further investigated by means of the Simon task. It was suggested that in the Simon task, active suppression is needed to resolve the conflict (Ridderinkhof, 2002a; see also Burle, Possamaï, Vidal, Bonnet & Hasbroucq, 2002). Given the similarities with the flanker task, it seems reasonable to assume that in a Simon task stopping would also be prolonged when the location of the stimulus is incompatible with the response side. However, contrary to the findings with the flanker tasks (Kramer et al., 1994; Ridderinkhof et al., 1999; Verbruggen et al., 2004, in press a), response inhibition in the stop signal task does not seem to interact with a *pure* stimulus-response compatibility (SRC) task. In a pure SRC task (e.g., press left when the arrow is pointing to the right), participants have to suppress overlearned responses to the stimuli. The compatibility effect - or the SRC effect *proper* - is due to an overlap between the relevant stimulus feature (i.e., the direction of the arrow) and the response set (e.g., left- and right-handed responses). Although van den Wildenberg and van der Molen (2004) found a compatibility effect on the CRTs on no-signal trials, this effect was not reflected in the SSRTs. Logan and Irwin (2000) also found no prolongation of the SSRTs with an incompatible response mapping. In addition, their data lacked a compatibility effect for responses to centrally presented arrows. In the light of the findings with the flanker task, this seems quite odd and the question will be whether the same null-results are found with the Simon task.

In sum, in the Simon task, the same inhibitory mechanism as in the arrow version of the flanker task is suggested (Ridderinkhof, 2002a). Therefore, if the suppression mechanism is indeed the same in both types of tasks, one would expect an interaction between the stop signal task and active suppression in the Simon task. On the other hand, the Simon task is an example of an SRC task and results with the pure SRC tasks, suggests that there is no interaction between SRC effects and stopping responses. In Experiment 1, the traditional horizontal Simon task was used (e.g., Craft & Simon, 1970), together with its vertical alternative in a between-subjects design. This extra vertical dimension was incorporated to provide an immediate extension of the findings with the traditional horizontal Simon

task. The main question was whether response stopping on incompatible trials was prolonged compared to compatible trials. Furthermore, it will provide a basis to compare the effects of stimulus and response compatibility on stopping responses in Experiment 2.

EXPERIMENT 1

METHOD

Participants

Forty-eight first-year psychology students at Ghent University (Belgium) participated for course requirements and credits. All participants had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment. Twenty-four participants (21 females and 3 males) did the experiment with a horizontal Simon task and twenty-four participants (18 females and 6 males) did the experiment with a vertical Simon task. One participant who participated in the experiment with the vertical Simon task was excluded from further data-analysis because of negative SSRTs.

Apparatus and signals

The experiment was run on a Pentium 4 PC running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press). Stimuli were presented on a 17-inch monitor placed at a distance of 60 cm in front of the participants. The stimuli were a red or green filled circle with a radius of 0.5° . In the horizontal Simon task, the stimuli were presented at the left or the right of the centre of the screen with a distance of approximately 2.5° . In the vertical Simon task, the colored circles were presented above or below the centre of the screen, also with a distance of 2.5° . Responses were collected via a response box connected to the parallel port of the PC. There was a distance of 15 cm between the two buttons. In the vertical Simon task, the response boxes were turned 90 degrees. Doing so, the left and right response button became the upper and lower button and participants were

instructed to place their dominant hand above their non-dominant hand. Occasionally, a loud and clear auditory stop signal (750Hz, 50 dB, 75 ms) was presented through closed headphones (Sennheiser HD 265-1) shortly after the stimulus onset in the CRT task.

Tasks and Procedure

The CRT task was to react to the color of the stimulus. In the horizontal Simon task, the color was mapped on the index finger of the left- and right hand. In the vertical variant, the color was mapped on the index finger of the upper- and lower hand (e.g., for a red circle, press the upper button). In both variants of the Simon task, the mapping was counterbalanced across participants. Trials belonged to two different conditions: Stimulus-Response Compatible (SRC; when the position of the stimulus corresponds to the side of the response) and Stimulus-Response Incompatible (SRI; when there is a mismatch between the response side and the position of the stimulus). The two types of stimuli occurred with equal probability. Each trial started with the presentation of a white fixation cross ($1.5^\circ \times 1.5^\circ$) in the centre of the screen, for 500 ms. The stimuli were presented for 150 ms and required a response within 1,500 ms. When the stop signal inhibition succeeded, the trial also ended after 1,500 ms. The next trial was presented 1,000 ms after the response.

The experiment consisted of two parts, one with and one without occasional presentation of stop signals. Each part started with a practice phase, followed by the experimental phase. The order of the parts was counterbalanced across participants. Participants received oral instructions. During the practice phase, participants also received immediate feedback. The screen colored red for 100 ms after an error and colored orange when participants responded after a stop signal was presented. During the experiment, participants received feedback at the end of each block only: The number of errors made during the block and the mean CRT. In the condition with stop signals, the mean probability of stopping was also presented.

In the part without stop signals, there was one practice block of 20 trials and two experimental blocks of 80 trials. The part with stop signals consisted of one practice block of 40 trials and eight experimental blocks of 80 trials. On a random selection of 30% of the trials, a stop signal was presented (signal trials). This resulted in 96 stop trials for the two types of stimuli. The stop signal delay was initially set at 250 ms and continuously adjusted according to separate staircase tracking procedures (Levitt, 1970) for each type of stimulus to obtain a probability of stopping of .50. Each time a participant responded to the stimulus in presence of a stop signal, the stop signal delay (SSD) decreased with 50 ms. On the other hand, when inhibition succeeded, the SSD increased with 50 ms. Based on the assumptions of the horse-race model, SSRT can now be calculated by simply subtracting 'mean SSD' from the untrimmed 'mean CRT' (Logan, 1994; Logan, Schachar & Tannock, 1997). The instructions emphasized both speed and accuracy. Furthermore, to avoid waiting strategies, participants were informed about the tracking procedure and they were told that the probability of stopping would approximate .50, irrespective of whether they were postponing their response or not. The duration of the whole experiment approximated 45 minutes.

RESULTS & DISCUSSION

CRT data of trials without stop signal presentation (no-signal trials) were subjected to a separate within-participant trimming procedure for each type of stimulus. Mean CRTs of correct trials were calculated after removal of outlying CRTs; i.e., CRTs longer than 2.5 standard deviations above the mean were discarded from data analysis. This resulted in a data reduction of 2.2%. Mean error percentage was 2.8%. The error data were not further analyzed.

No-signal trials

The no-signal data are presented in Table 3.1. CRTs were analyzed by means of an ANOVA with one between-subjects variable (dimension:

Horizontal vs. vertical) and two within-subjects variables: (1) block type (blocks with vs. blocks without occasional presentation of stop signals) and (2) compatibility (SRC vs. SRI). Main effects were found for both the block type and the compatibility. Participants were faster when no stop signals could occur during the block, $F(1,45) = 76.75, p < .001$, and when the trials were stimulus-response compatible, $F(1,45) = 78.56, p < .001$. The interaction between both main effects was also significant, $F(1,45) = 27.82, p < .001$, indicating that the compatibility effect was bigger in the blocks without stop signals. Besides these effects of the within-subjects variables, there was also a main effect of the dimension. Participants were generally faster in the horizontal Simon task, $F(1,45) = 4.39, p < .05$. This effect interacted also significantly with the effect of compatibility, $F(1,45) = 5.04, p < .05$, suggesting that the compatibility effect was more pronounced on the vertical dimension (33 ms vs. 20 ms). The type of task did not interact with the effect of block type, $F(1,45) < 1$. The three-way interaction was also not significant. Finally, post-hoc two tailed t-tests revealed that in the horizontal Simon task, the compatibility effect was present in both conditions, $t(23) = -2.63, p < .05$ with, and $t(23) = -4.98, p < .001$, without stop signals. Similar results were found in the vertical variant. The Simon effect was present in both the blocks with, $t(22) = -6.04, p < .001$, and without stop signal, $t(22) = -8.45, p < .001$.

Table 3.1: Reaction times (SDs in parentheses) of compatible (SRC) and incompatible (SRI) trials for both blocks with and without stop signals (S-S) in Experiment 1.

	Horizontal Simon task		Vertical Simon task	
	SRC	SRI	SRC	SRI
Without S-S	355 (33)	383 (28)	380 (59)	421 (56)
With S-S	459 (70)	471 (66)	483 (89)	508 (83)

Signal trials

Signal data were analyzed by means of a repeated measures ANOVA with compatibility as within-subjects variable and dimension of the Simon task as between-subjects variable. The results are presented in Table 3.2. First, for signal-respond trials a compatibility effect was found, $F(1,45) = 86.25, p < .001$. There was no main effect of the dimension, $F(1,45) < 1$, nor an interaction between the dimension and the Simon effect, $F(1,45) = 1.70, p = .19$. Secondly, the probability of responding given a stop signal did not differ between compatible and incompatible trials, $F(1,45) < 1$. The probability of responding was a bit higher in the horizontal task, $F(1,45) = 5.42, p < .05$, but this effect of dimension did not interact with the Simon effect, $F(1,45) < 1$. Third, there was a significant effect of compatibility on SSDs, $F(1,45) = 10.95, p < .01$. SSDs were not influenced by dimension, $F(1,45) = 1.69, p = .20$. The interaction was also not significant, $F(1,45) = 1.20, p = .28$. Finally, the SSRTs were analyzed. There were no effects of compatibility or the dimension, both F -values < 1 . There was also no interaction, $F(1,45) < 1$.

Table 3.2: Mean stop signal reaction times (SSRT_{all}), stop signal reaction times after compatible trials (SSRT_{SRC}), stop signal reaction times after incompatible trials (SSRT_{SRI}), mean probabilities of responding given a stop signal (P|resp), mean stop signal delay (SSD), and mean observed signal-respond RTs (SRT) in Experiment 1 for compatible (SRC) and incompatible (SRI) trials.

	Horizontal Simon task		Vertical Simon task	
	SRC	SRI	SRC	SRI
SRT	407 (58)	432 (55)	418 (78)	451 (71)
SSRT _{all}	180 (54)	181 (62)	164 (39)	169 (47)
SSRT _{SRC}	174 (51)	185 (60)	157 (40)	171 (47)
SSRT _{SRI}	185 (58)	175 (67)	169 (42)	167 (50)
P resp (%)	51 (3.2)	51 (4.7)	49 (1.7)	49 (1.5)
SSD	287 (105)	296 (107)	322 (111)	341 (95)

Discussion

On no-signal trials, a compatibility effect was found for both dimensions of the Simon task. Also, this compatibility effect was bigger in the blocks where no stop signals could occur. This is probably due to the fact that in the no-stop signal condition responses were faster. After all, participants tend to slow down their responses when stop signals could occur (Logan, 1994) and it is a common finding in the literature about the Simon task that with increasing RT, the Simon effect decreases (e.g., Hommel, 1993; Simon, Acosta, Mewaldt, & Speidel, 1976). This interaction between block type and the Simon effect was not influenced by the dimension. Furthermore, participants were faster in the horizontal Simon task (417ms vs. 448 ms), but on the other hand, the Simon effect was smaller with this dimension in comparison with the vertical dimension. This interaction seems to suggest that the vertical variant of the Simon task is not just a slower version of the traditional horizontal version of the task. Moreover, the horizontal compatibility effect is usually stronger compared to the vertical effect when the stimulus location could vary across the vertical and horizontal dimension (see e.g., Hommel, 1996; Rubichi, Nicoletti, & Umiltà, 2005; Proctor & Vu, 2002). Thus, the data of the Experiment 1 seem to suggest that this stronger horizontal Simon effect only holds when both dimensions are combined together.

On signal trials, there was a Simon effect when participants responded in spite of the presentation of a stop signal. This is not surprising, since it was suggested that these signal-respond trials generally correspond to the faster part of the no-signal CRT curve (Logan, 1994). A similar compatibility effect was found for SSDs. But most importantly, there was generally no influence of compatibility on response inhibition, indicated by comparable SSRTs for compatible and incompatible trials. However, as will be demonstrated in the next paragraphs, it may be that this lack of interaction is influenced by the trial sequence in the Simon task.

SEQUENTIAL ANALYSIS

In Experiment 1, stopping performance was not influenced by the compatibility of the trial. Given the findings in the flanker task, this may seem quite odd. However, the trial sequence may have influenced this interaction. After all, in conflict tasks, such as the flanker task and the Simon task, it is a common finding that the compatibility effect is smaller or even absent after an incompatible trial (e.g., Gratton, Coles, & Donchin, 1992). There are two main explanations for the sequential effect. First, it was suggested that this finding is evidence for top-down conflict monitoring. After an incompatible trial, performance would be adjusted in order to overcome the compatibility effect on the next trial (e.g., Gratton et al., 1992; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). On the other hand, a bottom-up explanation was suggested by several authors (Hommel, Proctor & Vu, 2004; Mayr, Awh, & Laurey, 2003; Notebaert, Soetens & Melis, 2001). For example, Hommel et al. (2004) argued that conflict adaptation pattern in the Simon task is due to the sequence of specific stimulus-response features, without the need for active top-down adjustments.

For the purpose of the present paper, the finding that there is no Simon effect after an incompatible trial may have important implications. Therefore, in order to investigate whether the compatibility of the previous trial could have influenced the interaction between stopping responses and the compatibility of the current trial, we will perform sequential analyses for both no-signal data and signal data. For CRT data, presented in Table 3.3, a repeated measures ANOVA was performed with one between variable (dimension) and three within-subjects variables: (1) compatibility of the trial n , (2) compatibility of trial $n-1$, and (3) the block type (i.e., blocks with vs. blocks without occasional stop signal presentation). The reported analyses are restricted to the effects related to the compatibility of the previous trial. First, we found a trend for the effect of trial $n-1$, $F(1,45) = 3.19$, $p = .08$. This effect of compatibility of trial $n-1$ interacted with the Simon effect on trial n , $F(1,45) = 110.42$, $p < .001$, suggesting that the Simon effect was more

pronounced after a compatible trial. The three-way interaction with block type was also significant, $F(1,45) = 14.74$, $p < .01$, indicating that the sequential modulation was stronger in the blocks with stop signals. None of these effects on stop signal inhibition was influenced significantly by the dimension of the Simon task (all F-values were smaller than $F(1,45) = 1.09$, $p = .30$).

In order to investigate the sequential modulation of the Simon effect in SSRTs, mean CRTs of no-signal trials and mean SSDs were calculated for trials following compatible and incompatible trials separately.¹⁶ Interestingly, for SSRTs the same interaction between compatibility of trial n and trial $n-1$ as in no-signal data was found, $F(1,45) = 12.06$, $p < .01$. None of the analyses concerning the effect of dimension reached significance, all F-values < 1 . Therefore, both dimensions were combined for subsequent analyses. After an incompatible trial, there was no effect of SRC on SSRT [177 ms vs. 171 ms, $t(47) = 1.24$, $p = .22$]. However, after a compatible trial, a significant Simon effect was found, [166 ms vs. 178 ms, $t(47) = -3.00$, $p = .01$].

This suggests that active suppression of the incorrect response and stop signal inhibition interact in the Simon task, but only when the previous trial was stimulus-response compatible. In other words, the results of the sequential analysis demonstrated that not only the CRTs are influenced by the compatibility of the previous trial, but that also the SSRTs are influenced, indicating that stopping responses on an incompatible trial is only prolonged when the previous trial was compatible. This is probably due to the fact that on the one hand, after an incompatible trial, there is no difference between compatible and incompatible trials, as demonstrated by the serial analyses for CRTs. On the other hand, after a compatible trial, incompatible trials are slower than compatible trials, due to the interference.

¹⁶ Probability of stopping was still .51 after both types of trials. Moreover, there were approximately 48 stop signal trials for both compatible and incompatible stimuli when the compatibility of the previous trial was taken into account (96 stop trials for both types, divided by 2 since there was a chance of .50 that the previous trial was for example compatible). Therefore, $SSRT_{\text{mean}}$ could still be estimated reliably.

Based on the activation-suppression hypothesis of Ridderinkhof (2002), this interference or conflict calls for a suppression of the irrelevant response, and it is this active suppression that interacts with the stopping of responses in the stop signal task.

Table 3.3: Reaction times (SDs in parentheses) of compatible and incompatible trials in function of the compatibility of the previous trial for both blocks with and without stop signals (S-S) in Experiment 1 (C-C: compatible-compatible; C-IC: compatible-incompatible; IC-C: incompatible-compatible; IC-IC: incompatible-incompatible; C-CE: compatibility effect for trials following compatible trials; IC-CE: compatibility effect for trials following incompatible trials).

	Horizontal Simon task		Vertical Simon task	
	Without S-S	With S-S	Without S-S	With S-S
C-C	349 (36)	453 (71)	367 (51)	496 (120)
C-IC	395 (28)	475 (64)	432 (52)	532 (108)
IC-C	369 (35)	468 (68)	392 (62)	507 (118)
IC-IC	380 (31)	469 (71)	413 (52)	520 (112)
C-CE	46	22	65	36
IC-CE	11	1	21	13

EXPERIMENT 2

In Experiment 1, an interaction between the Simon task and response inhibition in the stop signal task was found for both the horizontal and vertical dimension, similar to the interaction between response inhibition and congruency tasks like the flanker task. In both types of tasks, irrelevant stimulus information is present. When the irrelevant stimulus information is incompatible with the relevant information, interference arises. This interference needs to be resolved, and subsequently, it is found that this interference control in both the flanker task and the Simon task interacts with stopping in the stop signal task. In Experiment 2, this interaction with the stop signal task is directly compared for both types of compatibility

tasks. In Experiment 2 the spatial Stroop effect and the Simon effect were combined independently on a trial-by-trial basis.

In another study designed to compare the spatial Stroop effect and the Simon effect, Liu, Banich, Jacobson, and Tanabe (2004) used an integrated Simon and spatial Stroop task. In the spatial Stroop task, compatibility results from an overlap between the irrelevant stimulus (location) and the relevant stimulus dimension (up- or downward pointing arrow, mapped on left or right response key). In S-S compatible trials, an upward pointing arrow is shown above the fixation cross, whereas in S-S incompatible trials an upward arrow is presented below fixation cross. The Simon effect results from an overlap between the irrelevant stimulus location and the response location (see Figure 3.1). Thus, in the integrated spatial Stroop/Simon task, the irrelevant stimulus feature - i.e., the task irrelevant location of the arrows - is for both tasks the same. However, it is argued that the type of conflict differed. The Spatial Stroop task (i.e., when the arrows appear above or below the centre of the screen) is an example of an SSC task, whereas the Simon task (i.e., when the arrows appear on the left or the right of the centre of the screen) is an SRC task. fMRI data of Liu et al. (2004) demonstrated that although both interference effects are caused by different types of conflict, common activation in the dorsolateral prefrontal cortex was found. These authors argued that this dorsolateral activation was due to the fact that both tasks require attentional control in order to resolve the interference due to the presence of irrelevant stimulus information. But, besides this common activation, they found also a clear distinction between both types of conflict. Regions associated with response selection and response planning were only active in the Simon task (e.g., the ACC and (pre)supplementary motor areas) and regions associated with the task-relevant attribute (e.g., inferior parietal cortex) were more active in spatial Stroop task. It was suggested by Liu et al. (2004) that this difference in activation was determined by the difference in the type of conflict.

In Experiment 2, this integrated spatial Stroop/Simon task was combined with the stop signal task. In both tasks, the same stimuli and response mapping are used. A compatibility effect is expected for both tasks on CRTs but also on SSRTs. However, given the finding of Liu et al. (2004)

that also distinct regions were activated in both tasks, the experiment allows us also to compare directly whether the Simon task and the spatial Stroop task would influence stopping responses differently.

METHOD

Participants

Twenty-six paid volunteers (18 females and 8 males; mean age: 22.0 years, SD: 2.59) participated. All of them had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment.

Apparatus and signals

Only changes in comparison with Experiment 1 are discussed. The experiment was run on a Toshiba notebook and stimuli were presented on an external 17-inch monitor. The stimuli were white arrows presented on a black background. The maximum visual angle subtended by an arrow was approximately $2^\circ \times 1.8^\circ$. There were four different locations around the centre of the screen where the arrows could appear: Left, right, above and below, with a distance of approximately 2° (see Figure 3.1).

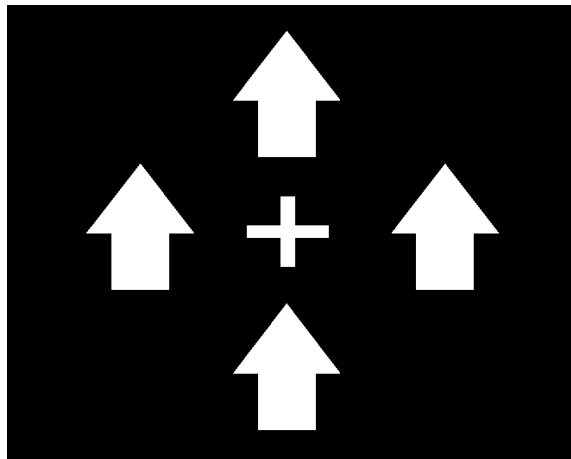


Figure 3.1: Four possible stimulus locations in Experiment 2.

Tasks and Procedure

Only the changes in comparison with Experiment 1 are discussed. The CRT task was to react to the direction of the arrow which was mapped on the left- and right hand. The mapping was counterbalanced across participants. The response buttons were aligned horizontally. For one half of the participants, upward pointing arrows required a left-handed response and downward pointing arrows required a right-handed response. For the other half of participants, the reversed mapping was used. This resulted in four different conditions: *Stimulus-Response Compatible* (e.g., in case of upward-left mapping, an upward pointing arrow was presented on the left of the centre of the screen), *Stimulus-Response Incompatible* (an upward pointing arrow presented on the right of the centre of screen), *Stimulus-Stimulus Compatible* (an upward pointing arrow above the centre of the screen) and *Stimulus-Stimulus Incompatible* (an upward pointing arrow below the centre of the screen). The four types of stimuli occurred with equal probability and were randomized, with the restriction that no response or stimulus type appeared more than three times in a row. The course of a trial was the same as in Experiment 1. The experiment consisted of two parts, one with stop signals and one without. This resulted in 8 blocks with stop signals (48 stop signals for each trial type) and two blocks without stop signals.

RESULTS AND DISCUSSION

CRT and error data were subjected to the same within-participant trimming procedure as in Experiment 1. This resulted in a data reduction of 2.0%. Participants made few errors (2.9%), so we did not further analyze the error data. Stop signal latencies are also estimated according to the same procedures as in Experiment 1.

No-signal trials

First, CRT data of the no-signal trials are presented in Table 3.4. They were analyzed by means of a 2 (block type: Blocks with vs. without stop

signal presentation) \times 2 (task: Stroop vs. Simon) \times 2 (compatibility) repeated measures ANOVA. Main effects were found for block type and compatibility. Participants were faster when no stop signals were presented, $F(1,25) = 39.5, p < .001$, and when the trials were compatible, $F(1,25) = 159.5, p < .001$. The interaction between these two main effects was also significant, $F(1,25) = 14.00, p < .001$, indicating that the compatibility effect was larger in the condition without stop signals. Unlike the effects of block type and compatibility, there was no main effect of task, $F(1,25) < 1$. The interactions between tasks and the effects of block type and compatibility were also not significant (both F -values < 1). However, the three-way interaction was significant, $F(1,25) = 5.73, p < .05$., indicating that the difference in compatibility effects between the two block types was a bit more pronounced in the spatial Stroop task (48 ms vs. 26 ms), compared to the Simon task (39 ms vs. 33 ms). But altogether, these analyses demonstrate that both types of trials were processed equally fast and that the compatibility effect was comparable in the Simon and the Stroop task, replicating the finding of (Liu et al, 2004). Post-hoc two tailed t-tests were performed for tasks separately. In the condition without stop signals, there was a Stroop effect, $t(25) = -9.17, p < .001$, and a Simon effect, $t(25) = -7.49, p < .001$. Similar results were obtained in the condition with stop signals. Again, a Stroop effect was observed, $t(25) = -5.70, p < .001$, together with a Simon effect, $t(25) = -7.63, p < .001$.

Table 3.4: Reaction times (SDs in parentheses) for both blocks with and without stop signals (S-S) in Experiment 2.

	Tasks			
	Spatial Stroop		Simon	
	Compatible	Incompatible	Compatible	Incompatible
Without S-S	447 (51)	495 (54)	451 (49)	490 (58)
With S-S	542 (81)	568 (76)	538 (82)	571 (77)

Finally, in the blocks with stop signals the compatibility effects in both tasks were also investigated as a function of the previous trial (there were not sufficient trials in the blocks without stop signals to perform these sequential analyses also in those blocks). For each task separately, the data were analyzed by means of a 2 (compatibility of the previous trial) by 2 (compatibility of the current trial) repeated measures ANOVA. Only the interactions are reported. As can be seen in Figure 3.2, the Stroop effect was influenced by the compatibility of the previous trial, but only for stimulus-stimulus compatibility, $F(1,25) = 20.63, p < .001$. Preceding stimulus-response compatibility had no effect on the stimulus-stimulus compatibility effect, $F < 1$. Similarly, the Simon effect was influenced by the stimulus-response compatibility of the previous trial, $F(1,25) = 9.49, p < .01$, but not by the stimulus-stimulus compatibility of the previous trial, $F < 1$.

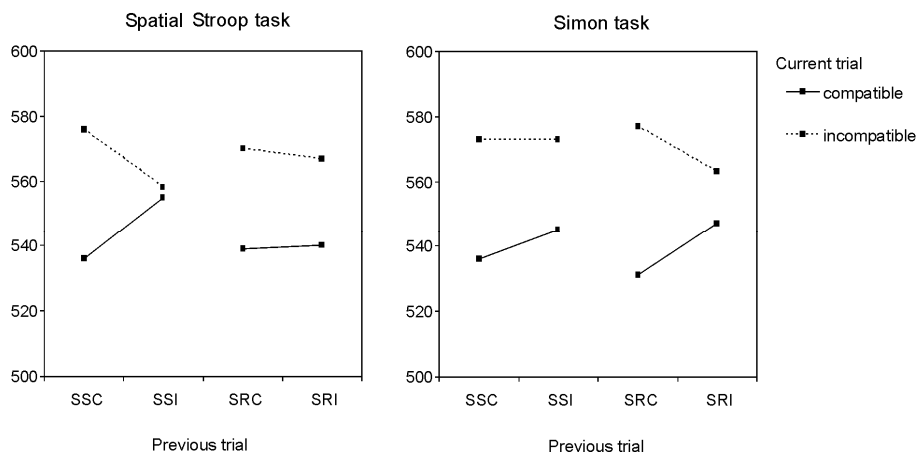


Figure 3.2: Compatibility effects for RTs in the Stroop and the Simon task separately in function of the previous trial (Stimulus-Stimulus Compatible, Stimulus-Stimulus Incompatible, Stimulus-Response Compatible, and Stimulus-Response Incompatible) in Experiment 2 (RTs are in milliseconds).

Signal-trials

Stopping data are presented in Table 3.5, and were analyzed by means of a 2 (task: Stroop vs. Simon) by 2 (compatibility) repeated measures ANOVA. For the probability of responding given a stop signal no effects or interactions were found (all F -values < 1). There was also no difference between the stop signal delays of both tasks, $F(1,25) < 1$. The SSDs of compatible trials tended to be shorter than the SSDs of incompatible trials, $F(1,25) = 3.98$, $p = .06$. The interaction was not significant, $F(1,25) = 1.12$, $p = .30$. We found similar results for the SSRTs. There was no difference between the SSRTs of the Stroop and Simon task, $F(1,25) < 1$. However, there was a main effect of compatibility, $F(1,25) = 7.18$, $p < .05$, indicating that in general, stopping was slowed down when trials were incompatible. The interaction between compatibility and task was not significant $F(1,25) < 1$. Two-tailed t -tests revealed that in both tasks, the compatibility effect was present in SSRTs. In the spatial Stroop task, stopping the response in compatible trials was faster than incompatible trials, $t(25) = -2.38$, $p < .05$. Likewise, in the Simon task stopping responses was faster in compatible than in incompatible trials, although this effect was only marginally significant, $t(25) = -1.91$, $p = .07$.

Table 3.5: Stop signal reaction times (SSRTs), probabilities of responding given a stop signal (P|resp), stop signal delay (SSD), and observed signal-respond RTs (SRT) in Experiment 2.

	Tasks			
	Spatial Stroop		Simon	
	Compatible	Incompatible	Compatible	Incompatible
SRT	496 (90)	530 (61)	488 (70)	527 (66)
SSRT	222 (35)	240 (51)	221 (39)	237 (49)
P resp (%)	49 (4.3)	49 (4.6)	49 (3.6)	49 (4.1)
SSD	326 (85)	334 (97)	323 (92)	339 (91)

In this experiment, there are not enough trials to do the extra analysis for SSRTs as a function of compatibility of the previous trial. Band et al. (2003) demonstrated that at least 40 signal trials are needed to obtain a reliable estimation of the SSRT and there are only approximately 24 stop-signal trials when the compatibility of the previous trial is taken into account.

In general, Experiment 2 showed that both SSC and SRC affect the CRTs and SSRTs. Stopping took longer when a trial was SS or SR incompatible. It was not possible to investigate the interaction between both effects since a trial is only SSC (stimulus above or below fixation cross) or SRC (stimulus left or right of fixation cross) and never a combination of both. For CRTs, we observed again (as in Experiment 1) that the compatibility effect is modulated by the compatibility of the previous trial. An SSC effect was only present after SS compatible trials and the Simon effect was only present after Simon compatible trials. In contradiction to Experiment 1, there was an overall effect of compatibility on SSRT.

GENERAL DISCUSSION

In the present study, we investigated the relation between the Simon task and the stop signal task. Previous studies demonstrated that stopping responses in the stop signal task was slowed down when a trial was stimulus-stimulus incompatible (Kramer et al., 1994; Ridderinkhof et al., 1999; Verbruggen et al., 2004, in press a). This result was interpreted as evidence for the hypothesis that interference control in congruency tasks and response inhibition in the stop signal task may rely on the same mechanisms (Logan, 1994; Ridderinkhof et al., 1999; Verbruggen et al., 2004, in press a). In a congruency task like the flanker task, irrelevant stimulus information interferes with the processing of the relevant stimulus features. This interference needs to be controlled and an active suppression mechanism is proposed to explain the RT cost in case of incompatible trials (Burle et al., 2002; Ridderinkhof, 2002a) and Ridderinkhof et al. suggested that this suppression mechanism interacted with the stopping of responses in the stop signal task. Furthermore, Ridderinkhof (2002) proposed a similar

explanation for the Simon effect and the compatibility effect in the flanker task.

Therefore, if the hypothesis of a central inhibitory mechanism as suggested by Ridderinkhof (2002) is correct, it is expected that interference control in the Simon task would also interact with stopping responses. In Experiment 1, we investigated this hypothesis and used two different variants of the Simon task. Stimuli were presented on a horizontal or a vertical dimension. Response mappings were manipulated according to the same dimensions. CRT data for both dimensions were straightforward. Although the size of the compatibility effect was influenced by both the dimension and the occasional presentation of stop signals, participants responded generally faster when the location of the stimulus and the response side were the same. When participants responded even though a stop signal was presented, we found also a clear Simon effect. However, at first sight, there was no effect on stopping responses. However, when the trial sequence was taken into account, the compatibility influenced SSRTs.

It appeared that stopping was more difficult in stimulus-response incompatible trials, but only when the previous trial was stimulus-response compatible. A sequential analysis of the no-signal data demonstrated that the Simon effect decreased for CRTs when the previous trial was incompatible. As can be seen in Table 3.3, the SRC effect was even absent after an incompatible trial for the horizontal dimension. Therefore, it seems reasonable that after an incompatible trial, no interaction between compatibility and response inhibition can be found since no Simon effect is present. After all, when there is no conflict present on the current trial, it follows that there is no need for an active suppression of the incorrect response codes in case of the Simon task. And of course, when there is no active suppression in the current trial, there is no interaction with the stopping of responses in the stop signal task.

Thus, in Experiment 1, it was demonstrated that the Simon effect (an SRC-effect) influenced stopping responses, similar to the way the flanker effect (an SSC-effect) influenced stopping responses. In Experiment 2, we compared directly the effect of SSC in a spatial Stroop task and the Simon effect on stopping responses in the stop signal task. Via an integrated spatial

Stroop/Simon task, both types of conflict were operationalized within blocks. This task was also used by Liu et al. (2004) in an fMRI study. They found that both tasks activated the same prefrontal regions. On the other hand, the different types of conflict resulted also in exclusive and task-specific activation of regions for both tasks. Notwithstanding these differences, both the analyses of no-signal data and signal data clearly demonstrated that both types of conflict were comparable for the different measures. First, mean CRTs did not differ and also the effect of compatibility was the same in both tasks. Secondly, there was an overall effect of compatibility on SSRTs and this effect was also not influenced by the task. We suggest that this finding provides further evidence for the hypothesis that interference control, by means of active suppression, in different conflict tasks is at least highly comparable. Moreover, the finding that stopping responses in the stop task is also influenced, seem to suggest that active inhibitory mechanisms are needed in both types of tasks and that this common need for active mechanisms causes the interaction found in the present study.

Another possibly interesting finding in Experiment 2 is that the Stroop effect disappeared only after a Stroop incompatible trial. This finding could not be generalized to all incompatible trials, since there was no interaction when the previous trials were Simon incompatible. The reverse pattern was observed for the Simon effect. In terms of top-down monitoring, it could be argued that due to the different types of conflict, the regions where the post-conflict adaptations take place, are also different. This would be in line with the findings of Liu et al. (2004) who found that the Simon task activated response-associated whereas in the spatial Stroop task, regions associated with the task-relevant attribute were more active. There was a common activation of the prefrontal regions – interpreted as evidence for top-down adjustments – but the regions of effect may be different in the spatial Stroop task and the Simon task. This could possibly explain why there was no effect of the Stroop task on the performance on the Simon task and vice-versa. However, top-down explanations for the sequential effects in this Experiment 2 (and also Experiment 1) are confounded with stimulus-response repetitions. Exact stimulus-response repetitions were not possible

when participants switched from one type of trial to another type of trial. Following the logic of bottom-up explanations (Hommel et al., 2004; Mayr et al., 2004; Notebaert et al., 2001), no modulation of the interference effect is expected when participants switched from one type of conflict (e.g., Stroop incompatible) to another type of conflict (e.g., Simon incompatible). Thus, both top-down and bottom-up accounts can explain the present data pattern.

Which of the two types of accounts (top-down vs. bottom-up) is correct, is still heavily debated, especially since the conflict monitoring pattern is found even when the design is carefully balanced against repetition effects (Wühr, in press) or when repetitions are excluded altogether (Kerns et al., 2004). However, we cannot control for these repetition effects since the experiments were not designed for this purpose. A last remark related to this issue is that we assume that there is an active suppression mechanism needed to resolve the interference in the current trial. But these adjustments are clearly within-trial adjustments to enable us to respond correctly within the presence of distracting information. This active form of control does not imply that trial-by-trial (or sequential) effects are also due to active mechanisms.

With regard to the observed interaction between the Simon task and the stop signal task, one important question remains. Although stimulus-response compatibility in the Simon task interacts with stopping responses, previous studies could not find an interaction between the suppression of spatially incompatible responses and response inhibition (Logan & Irwin, 2000; van den Wildenberg & van der Molen, 2004). However, there are at least two important differences between the SRC effect *proper* and the SRC effect in the Simon task. First of all, in the Simon task, the conflict is due to irrelevant stimulus information, whereas in a pure SRC task, the conflict is due to the relevant stimulus feature (e.g., press left when the arrow is pointing to the right). Note that in the flanker tasks, where also an interaction is found with the stop signal task, the conflict is also due to irrelevant stimulus features. Verbruggen et al. (2004, in press a) already argued that the suppression of irrelevant stimulus information, regardless whether this information is response related, caused the interaction with the

stop signal task. In the light of this explanation, it seems perfectly plausible that stopping is indeed prolonged in Simon incompatible trials. Also, with regard to the distinction between both types of SRC effects, this could imply that there is no interaction between stopping and the SRC effect *proper* because the interference is due to the relative stimulus feature in a pure SRC task. Of course, this response feature cannot be suppressed since a response is needed on the same feature. In other words, there is no place for selective suppression and thus, no interaction with the stop signal task.

Secondly, another possible difference between the two types of conflict is the fact that in a pure SRC task the manipulation is between-blocks. In this task, the compatibility effect is calculated as the difference between the performance in a compatible block and the performance in an incompatible block. In such a compatibility task, it was suggested that besides the interference in an incompatible trial, an incompatible stimulus-response mapping is also assumed to be more difficult since the natural SR mapping cannot be applied (Kornblum, et al, 1990). Both the interference and the SR mapping are supposed to contribute to the CRT difference in a pure SRC task. But in a pure SRC task, in an incompatible block all trials are incompatible, resulting in probably less interference. Thus, it might be possible that the CRT difference between the compatible and the incompatible blocks is mainly caused by a more difficult response selection in case of a non-natural SR mapping (e.g., press left when the arrow is pointing to the right). This would have important implications for the interaction with the stop signal task since Logan, Kantowitz, and Riegler (1986) already demonstrated that in a simple stop task, there is no effect when the response selection is made more difficult. Inhibiting one out of two responses was as difficult as inhibiting one out of four responses (Logan et al., 1986). On the other hand, this manipulation of response selection did affect the response inhibition in the selective stop signal task. This is also in accordance with the finding of van den Wildenberg and van der Molen (2004). These authors found that selective stopping was, contrary to simple stopping, influenced by the SRC effect *proper*. Thus it may be that the differences in a pure SRC task are mainly due to a more complicated response selection, and only to a lesser extent, to interference. Which of the

two differences (the type of information that causes the interference and the type of block manipulation) caused the interaction, is difficult to say. For example, it is possible that both differences between a pure SRC task and the Simon task, contribute both to the fact that there is no interaction between a pure SRC task and the stop signal task.

In conclusion, the present study found an interaction between the interference control in the Simon task and response inhibition in the stop signal task. This effect is comparable to the effect of stimulus-stimulus compatibility on response inhibition, and suggests that stimulus-response compatibility influences response inhibition. We argue that these findings provide further evidence for the hypothesis that in a congruency tasks or compatibility tasks, an active suppression mechanism is needed in order to resolve the conflict caused by the distracting irrelevant information (Burle et al., 2002; Ridderinkhof, 2002a). Moreover, we hypothesize that it is this active mechanism that causes the interaction with the stopping of responses, which is also clearly form of an executive act of control (Logan & Cowan, 1984).

CHAPTER 4 ON THE DIFFERENCE BETWEEN RESPONSE INHIBITION AND NEGATIVE PRIMING

In the previous two chapters, we have demonstrated that stop signal inhibition is influenced by the concurrently selective suppression of irrelevant stimulus features. In the taxonomy of Nigg (2000) both forms of inhibition (stop signal inhibition and interference control) lump together as 'effortful forms of inhibition'. Note that a third form of effortful inhibition (i.e., oculomotor inhibition in the antisaccade task), was also shown to interact with stop signal inhibition (Logan & Irwin, 2000). Furthermore, the results of Chapters 2 and 3 are in line with the findings of Friedman and Miyake (2004), who found that prepotent response inhibition and resistance to distractor interference were correlated. All in all, the results of previous studies and our studies suggest that there is an overlap between different kinds of effortful inhibition.

In the present Chapter, we will investigate whether similar results are found with a paradigm that is assumed to operationalize a less effortful form of inhibition: Negative Priming. The negative priming paradigm stems originally from the Stroop literature (Dalrymple-Alford & Budayr, 1966) and refers to the finding that participants are slower to respond to a target that had to be ignored on the previous trial. Thus, negative priming occurs when the irrelevant stimulus information was selectively suppressed on trial $n-1$. When this irrelevant feature becomes the relevant stimulus feature on trial n , responses are slowed down. Several explanations have been offered for the negative priming effect, which is in a sense an after-effect of the active selective suppression that we have investigated in Chapters 2 and 3.

In the introduction, it was already mentioned that negative priming is considered as an automatic form of cognitive inhibition in the taxonomy of Nigg (2000). Friedman and Miyake (2004) also looked at the correlation between negative priming and the different forms of inhibition and did not find any correlation. Thus, it remains to be investigated whether the effortful stop signal inhibition can be influenced by a more automatic form of

inhibition like negative priming. Then again, if negative priming is indeed due to persisting inhibition of the distractor as suggested by several researchers (e.g., Houghton & Tipper, 1994; Tipper, 1985), then it could be the case given the findings of Chapters 2 and 3 that stop signal inhibition is indeed influenced by negative priming.

There is yet another reason to expect some mutual interference between stop signal inhibition and negative priming. Kramer, Humphrey, Larish, Logan, and Strayer (1992), cited by Logan (1994), observed that participants were slower when a stop signal was presented on the previous trial. Rieger and Gauggel (1999) further investigated this result and found that the effect of stop signal presentation was stronger when (a) the inhibition failed and (b) when the primary task properties were repeated. Based on these results, it was argued that this 'post-signal slowing down' was not only a strategic effect, but probably an effect related to negative priming. Consequently, an interaction between stop signal inhibition and negative priming can be expected.

In the study of the present chapter, a stop signal task was integrated in a regular negative priming design. There were two main research questions: (1) is stop signal inhibition influenced by the negative priming effect and (2) is there something in common in the 'post-signal slowing down' effect and in the negative priming effect, as suggested by Rieger and Gauggel (1999).

**ON THE DIFFERENCE BETWEEN RESPONSE INHIBITION
AND NEGATIVE PRIMING:
EVIDENCE FROM SIMPLE AND SELECTIVE
STOPPING^{17,18}**

Negative priming is a commonly observed after-effect in studies concerning inhibition. Effects of the preceding trial are also found in other paradigms, like the stop signal paradigm. In the present study, stop signals were introduced in a negative priming paradigm and the relation between stop signal inhibition and negative priming was investigated. In Experiment 1, we used a simple stop signal task. Stopping data clearly suggest that stopping performance was not influenced by negative priming. Interestingly, on no-signal probes the negative priming effect disappeared after successful inhibition of the response on the prime trial. On the contrary, when inhibition failed, the negative priming effect remained. In Experiment 2, we used the selective stop signal task. As in Experiment 1, inhibition of motor responses was not influenced by negative priming. The hypothesis that negative priming disappeared due to a general nonspecific stop was confirmed in this experiment, as a negative priming effect was found after both successful and unsuccessful behavioural inhibition. The results of both experiments show that response inhibition is not influenced by negative priming, and that negative priming is only affected after a successful general stop.

¹⁷Verbruggen, F., Liefoghe, B., & Vandierendonck, A. (2005). On the difference between response inhibition and negative priming: evidence from simple and selective stopping. *Psychological Research*, 69, 262-271.

¹⁸ We would like to thank an anonymous reviewer and Iring Koch for their useful comments on a previous version of this manuscript.

INTRODUCTION

The stop signal task (Lappin & Eriksen, 1966; Logan, 1994; Logan & Cowan, 1984) is one of the most frequently used tasks in the study of behavioural inhibition. In this stop signal paradigm (Logan, 1994; Logan & Cowan, 1984), participants usually perform a speeded choice reaction time task. Occasionally, stop signals are presented to inform the participants to withhold their response. On short stop signal delays (SSD; the interval between the presentation of the go signal and the stop signal), participants can easily suppress their response. By contrast, when the stop signal delay is long enough, participants will nearly always execute the response. Logan and Cowan (1984) developed the horse race model to explain these results. The model assumes a race between two processes: A go process and a stop process. If the stop process is completed before the go process, participants will inhibit their response (signal-inhibit trials). On the contrary, when the go process finishes before the stop process, participants will respond (signal-respond trials). Based on the assumptions of the horse-race model, it is possible to estimate the covert latency of stopping: The Stop Signal Reaction Time (SSRT; for reviews see Logan, 1994; Band, van der Molen, and Logan 2003). The SSRT has already proven its usefulness with different response modalities, like hand and foot movements (De Jong, Coles, & Logan, 1995), and in different populations such as children with attention deficit and hyperactivity disorder (ADHD; Jennings, van der Molen, Pelham, Debski, & Hoza, 1997) and older adults (Kramer, Humphrey, Larish, Logan, & Strayer, 1994).

The presentation of stop signals in a given trial also appears to affect performance in the subsequent trial. Kramer, Humphrey, Larish, Logan, and Strayer (1992), cited by Logan (1994), found that the go signal reaction time was slower in trials that followed successful response inhibition than in control trials. Rieger and Gauggel (1999) further investigated the effect of the presentation of a stop signal in trial n on the responses in trial $n + 1$ by using a simple discrimination task with occasionally a stop signal. They found that after the presentation of a stop signal in trial n , participants responded more

slowly in trial $n + 1$, compared with responses that followed on no-signal trials. These effects were even stronger when inhibition failed and when the primary task properties of trial n and trial $n + 1$ were the same. Rieger and Gauggel (1999) argued that strategic effects could therefore only partially explain their results and suggested a specific mechanism that is responsible for after-effects in different inhibitory tasks.

Nowadays, effects of the preceding trial on the next trial as found by Rieger and Gauggel are a common finding in the literature on inhibition. Dalrymple-Alford and Budayr (1966) were the first to find that in a Stroop task, responses were delayed when the target had previously been suppressed. This phenomenon is now called '*negative priming*'. It is a well established effect that when people have to ignore a stimulus in one trial (the prime trial) the reaction times in the subsequent trial (the probe trial) are prolonged (for reviews, see May, Kane, & Hasher, 1995; Fox, 1995). There are three main accounts of negative priming. The oldest account relies on a forward-acting suppression mechanism (e.g., Tipper & Cranston, 1985). According to the selective inhibition account, negative priming arises from the active suppression of the distractors of the prime trial. There are two main proposals for what actually becomes inhibited. Neill (1977) suggested that the mental representation of the distractor becomes suppressed, whereas the most frequently used proposal of Tipper and colleagues (Houghton & Tipper, 1994; Tipper & Cranston, 1985) suggested that the links between the representations and the response mechanisms are inhibited. Nonetheless, both proposals assume that when the suppressed distractor becomes the target of the next trial (ignored repetition), there is still residual inhibition from the prime display. This residual inhibition decays passively and causes the negative priming effect.

The other explanations of negative priming are memory-based accounts, suggesting that negative priming results from the implicit retrieval of previously stored information. Logan (1988) proposed in his 'instance theory of automatization' that each time a task is performed, information about the act is stored and later on retrieved from the memory. The episodic retrieval account for negative priming (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) is based on the above assumption. The probe trial is

supposed to act as a cue for retrieving information (or the 'episode') of the previous trial. Each episode contains information about the identity of the stimuli and the response they require ('respond' vs. 'do not respond'). In cases of ignored repetition, a conflict arises between the 'do not respond' tag of the prime display and the 'respond' tag of the probe display. This conflict must be resolved and delays the responding. This delay corresponds to the negative priming effect. Finally, the third explanation is the feature mismatch theory (Park & Kanwisher, 1994). Park and Kanwisher suggest that negative priming is due to differences between the representation of the distractor in the prime trial (e.g., a red colored 'H') and the target in the probe trial (e.g., a green colored 'H'). This partial mismatch causes interference and delays the processing of the target. However, negative priming is observed when there is no perceptual mismatch between the distractor of the prime and the target of the probe (e.g., Milliken, Tipper, & Weaver, 1994), and on the other hand, negative priming was absent when there was perceptual mismatching (Baylis, Tipper, & Houghton, 1997).

One important difference between the feature mismatch account and the episodic retrieval account is that the former localizes the conflict at a perceptual level. The episodic retrieval account, on the contrary, states that negative priming is caused by interference at the response level. Another difference between the two memory-based accounts is that according to the feature mismatch account there is no need for conflict in the prime trial. The episodic retrieval account and the selective inhibition account assume that negative priming is due to a conflict in the previous prime trial. Which of the three accounts is most suitable is still heavily debated. Recent results (e.g., MacLeod, Chiappe, & Fox, 2002) have been generally more in favor of a memory-based account. Note that according to Tipper (2001), differences between inhibitory and memory-based accounts lie especially in the emphasis on encoding and retrieval processes. Therefore, Tipper suggested that both accounts are needed to fully understand and explain negative priming.

In the present study, the relation between negative priming and inhibiting responses in the stop signal task is further investigated by introducing a stop signal in the traditional negative priming design. A

similar method has already proven useful in investigating the interaction between stop signal inhibition and other tasks that are assumed to require inhibition like the flanker task and the Stroop task (Ridderinkhof, Band, & Logan, 1999; Verbruggen, Liefoghe, & Vandierendonck, 2004). Stopping responses appeared to be slowed down by the presentation of categorically related distracting information, suggesting that stop signal inhibition and interference control in the flanker and Stroop tasks rely on common mechanisms. In contrast, several studies found no difference between the inhibition of spatially compatible responses and the inhibition of spatially incompatible responses (e.g., Logan, 1981). Therefore, it has been argued that resolving interference of spatially incompatible responses at response level and stopping behaviour do not interact (Logan, 1994).

By introducing stop signals in a negative priming paradigm, we would be able to investigate the reciprocal relation between stopping responses and negative priming. When negative priming and inhibition in the stop signal task rely on common mechanisms, an interaction as indicated by SSRT differences would be expected. On the one hand, when the link between the stimulus representation and response mechanism is already slightly suppressed as suggested by Tipper (Houghton & Tipper, 1994; Tipper & Cranston, 1985), stopping responses should be easier for ignored repetition trials. On the other hand, when the negative priming is due to interference from retrieved information as suggested by the memory-based accounts, stopping may be slowed down by analogy with the effects found with the flanker task and the Stroop task. Especially when the interference is indeed situated at a stimulus processing level, as suggested by the feature mismatch account, and not at a pure response level, this interaction should be found. Finally, finding no interaction demonstrates that different mechanisms are engaged in stop signal inhibition and negative priming, by analogy with the absence of interaction with spatially incompatible responses and stop signal inhibition.

Besides the effect of negative priming on stopping responses, after-effects of the stop signal task are also investigated by the presentation of stop signals in the prime trial. When the inhibitory after-effects of the stop signal task are similar to negative priming as suggested by Rieger and

Gauggel (1999), the presentation of stop signals in the prime trial should interact with the negative priming effect, whereas no overlap should result in an additivity of both effects. From the perspective of memory-based accounts, there are also reasons to expect an effect of stopping on negative priming. It seems plausible that the presentation of the stop signal and the response inhibition influences the processing and storage, resulting in a changed and probably smaller negative priming effect.

EXPERIMENT 1

METHOD

Participants

Twenty first-year psychology students at Ghent University (Belgium) participated for course requirements and credit. All participants had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment.

Apparatus and signals

The experiment was run on a Pentium PC. Stimuli were presented on a 17-inch monitor, placed at a distance of 50 cm in front of the participants. Stimuli were the letters 'F,' 'H,' 'L,' and 'T.' Each trial consisted of two letters, a green target letter and a red distractor letter, presented in central location on a black background. The letters appeared on both sides of the diameter of an imaginary circle with a radius of 0.5° . The maximum visual angle subtended by a letter was approximately $1^\circ \times 1^\circ$. Therefore, the letters could sometimes partially overlap, with the distractor always superimposed on the target. This overlap was only minimal and did not impede the recognition of the letters. Responses were collected with a response box connected to the game port of the PC. The four black buttons of the box were labeled with one of the four letters. All participants placed their index and middle fingers from their left and right hands on one of the buttons. Occasionally, a loud

and clear auditory stop signal (750 Hz, 70 dB, 50 ms) was presented shortly after the stimulus onset in the visual primary task.

Tasks and procedure

The primary task required the participant to respond to the green letter by pressing the corresponding button on the response box. Participants were instructed to respond as quickly and accurately as possible. Each pair of trials began with the presentation of a white fixation cross (0.75° x 0.75°) in the center of the screen. After 250 ms, the fixation sign was replaced by the first pair of letters, which was the prime trial. The prime trial was always incompatible, i.e., the target and distractor were different letters. The stimuli were presented for 150 ms and required a response within 1,500 ms of onset. After this first response, there was a response stimulus interval (RSI) of 350 ms. Again, the fixation cross reappeared and was replaced after 250 ms by the second pair of stimuli, the probe trial (Figure 4.1).

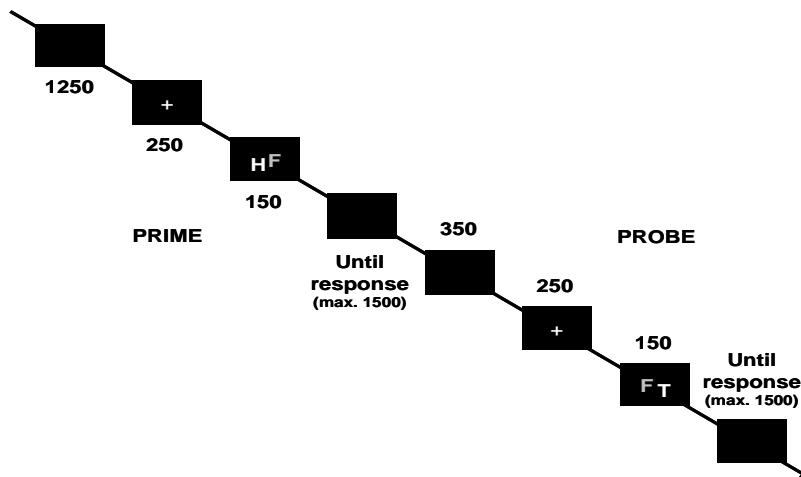


Figure 4.1: Trial sequence of a prime-probe pair. Durations are in milliseconds.

Half of the probe trials were control trials; i.e., both target and distractor were different from the stimuli of the prime trial. The other half of the probe trials were ignored repetitions. The distractor of the ignored repetition probe

did not appear in the prime display. Like the prime trials, all probe trials were incongruent. The order of the prime/probe pairs was randomized.

The experiment consisted of 10 blocks of 48 prime/ probe pairs and started with an extra practice block. In a random selection of 25% of the trials (i.e., 50% of the prime/probe pairs) a stop signal was presented. The signal could occur with equal probability in the prime and in the probe trials, with the restriction that there could be only one stop signal within a prime/probe pair. Therefore, probe signal trials always followed no-signal prime trials and after a signal prime trial, there was always a no-signal probe trial. This resulted in 60 stop prime trials followed by a control probe, 60 stop prime trials followed by an ignored repetition, 60 stop signals on a control probe, and finally 60 stop signals on an ignored repetition. The stop signal delay was initially set at 250 ms and was continuously adjusted according to a staircase tracking algorithm (Levitt 1970) for each type of trial to obtain a probability of stopping of 50%. Each time the participant responded to the stimulus in the presence of a stop signal, the stop signal delay decreased by 50 ms. On the other hand, after successful inhibition, the delay increased by 50 ms. This method provides SSRT estimations that are derived from the central part of the no-signal RT curve. Logan, Schachar and Tannock (1997; see also Band et al., 2003) demonstrated that 'central' estimates are relatively insensitive to violations of the horse-race model and therefore most reliable. In order to avoid 'waiting' strategies, participants were informed about the tracking procedure. They were told that the probability of stopping would approximate 50%, irrespective of whether they were postponing their response or not.

Stop latency estimation

Stop Signal Reaction Times were estimated as proposed by Logan and Cowan (1984), based on the horse-race model. According to this model, after rank ordering the choice reaction times (CRTs) of no-signal trials, the left, fast part of this CRT distribution is assumed to correspond to the distribution of CRTs of signal trials in which inhibition failed. By doing this, the finishing time of the stop process can be derived. The finishing time of

the stop process corresponds to the n th CRT of the no-signal trials, where n is the result of multiplying the total number of no-signal trials by the probability of responding when a signal is presented, given a certain SSD. Since the start of the inhibition process (mean SSD) and the finishing time are known, the SSRT can be estimated. The SSRT is obtained by subtracting the start time from the finishing time or ' n th CRT minus SSD' (see Logan, 1994).

RESULTS

The data of the probe trials were only considered for analysis after removal of the trials in which an error was made in the prime or in the probe trial. An alpha level of .05 was used for all statistical tests. Participants made few errors (mean: 5.6%). Because of missing cells in the data matrix, error data are not analyzed. Analysis of CRTs of no-signal probe trials and signal probe trials are reported separately. All reported analyses of CRT data are repeated measures ANOVA (lowest p value of the sphericity test was $p = .13$) and since ignored repetitions were expected to be slower, all post hoc tests were one-tailed t -tests.

No-signal trials

There were three types of no-signal probe trials: Probe trials without stop signal in the prime trial (no-signal), probe trials that followed a prime trial with a stop signal, but where the inhibition failed (signal-respond), and probe trials where the inhibition in the prime trials succeeded (signal-inhibit). Data were analyzed by a 2 (probe trial: Control vs. ignored repetition) \times 3 (signal property of the prime trial: No-signal, signal-respond, signal-inhibit) repeated measures ANOVA. Mean response times are presented in Table 4.1. We found significant effects of both factors. The first effect corresponds to the negative priming effect, $F(1, 19) = 6.49, p < .05$, the second was the effect of the presentation of a stop signal in the prime trial, $F(2,38) = 7.36, p < .01$. The interaction between both factors was also significant, $F(2,38) = 9.23, p < .001$. As can be seen in Table 4.1, there was a

reliable difference between control probe trials and ignored repetitions when participants responded to the prime target, regardless of the presentation of a stop signal; $t(19) = -4.70$, $p < .001$, for no-signal prime trials, and $t(19) = -3.15$, $p < .01$, for signal-respond prime trials. However, when inhibition of the response in the prime trial succeeded (i.e., signal-inhibit trials), the negative priming effect disappeared, $t(19) = 1.50$, $p = .08$.

To investigate whether there was an effect of the time between the presentation of the stop signal and the presentation of the next trial, we performed a median split on SSD. When the SSD of signal-inhibit prime trials was small (mean: 422 ms), participants responded faster in the probe trial (mean CRT = 709 ms) than in signal-inhibit prime trials with a large SSD (mean SSD = 608 ms; mean CRT = 768 ms), $F(1,19) = 9.65$, $p < .01$. As in the previous analysis, we found no main difference between control probes (mean CRT = 744 ms) and ignored repetitions (mean CRT = 733 ms), $F(1,19) = 1.45$, $p = .29$. The interaction with SSD length was not significant either, $F < 1$. We also looked for a general slowing down of the responses after the presentation of a stop signal, as found by Rieger and Gauggel (1999). Since the negative priming effect disappeared after signal-inhibit primes, we compared only the RTs of the control probes. A repeated measures ANOVA with stop signal as a within-subjects variable (signal properties of the prime trial: No signal, signal-respond, signal-inhibit) revealed no differences, $F < 1$.

Table 4.1: Reaction times of no-signal probe trials (SDs in parentheses) as a function of the presentation of a stop signal on the prime trial in Experiment 1. The negative priming effect was computed by subtracting the mean CRT of control probes from the mean CRT of ignored repetitions probes ($p < .01$).**

Priming condition	Prime trial		
	No signal	Signal-respond	Signal-inhibit
Ignored repetition	767 (102)	793 (99)	726 (109)
Control	750 (102)	754 (78)	739 (112)
Negative priming	17 **	39 **	- 13

Signal-trials

Half of the stop signals occurred in the probe trials. Stopping data as a function of priming were analyzed by a repeated measures ANOVA, with probe (control vs. ignored repetition) as a within-subjects variable. Stopping data are presented in Table 4.2. Probability to respond given a stop signal was .49 for both control and ignored repetition trials, $F < 1$. As can be seen in Table 4.2, neither the SSRTs of control and probe trials nor the SSDs of both types of probe trials differed, both $F_s < 1$. These findings clearly suggest that stopping is not influenced by negative priming. Finally, we tested for differences between CRTs of control probe and ignored repetitions when a stop signal was presented but where the inhibition failed. As in the other CRT analysis, we found a difference in signal-respond RT, $t(19) = -1.94$, $p < .05$.

Table 4.2: SSRTs, probabilities of responding given a stop signal, stop signal delay, and signal-respond RT in Experiment 1 (SDs in parentheses). The negative priming effect was computed by subtracting the mean CRT of control probes from the mean CRT of ignored repetitions probes (* $p < .05$).

	Priming Condition		
	Ignored repetition	Control	Negative priming
Stop signal RT	177 (45)	178 (49)	1
Response ratio (%)	48.9 (2.9)	49.3 (3.0)	0.4
Stop signal delay	546 (118)	552 (115)	6
Signal-respond RT	680 (92)	668 (85)	12 *

DISCUSSION

The results of this experiment are two-fold. First of all, SSRT analyses clearly indicate that stopping performance is not influenced by negative priming. The SSRTs for control probe trials and ignored repetitions did not differ. Secondly, the presentation of a stop signal in the prime trial does

affect performance in the control probes. Unlike Rieger and Gauggel (1999), we did not find a general slowing down of the responses after presentation of a stop signal in the prime trial. However, we found another after-effect of the stop signal inhibition. When inhibition of the response on the prime target succeeded, the negative priming effect completely disappeared and this did not depend on the time course of the stop signal task, as indicated by the split between short and long SSDs.

How do these results fit with the different accounts of negative priming? First of all, negative priming did not influence stop performance. Based on the assumption that negative priming is due to a suppressed link between the mental representation and the response mechanism, the selective inhibition account would predict a faster response inhibition for ignored repetition trials. Therefore, the stopping data are probably not in favor of the selective inhibition account as proposed by Tipper and colleagues. The stopping data could, however, easily be explained by the episodic retrieval account. According to this account, the conflict causing negative priming is situated at the response level. By analogy with the suppression of spatially incompatible responses, the results of the present experiment would indicate that resolving a response conflict in the negative priming task, causing the delay, and inhibiting a response in the stop signal task, rely on different mechanisms.

Secondly, negative priming disappeared after a successful stop. Since the memory-based accounts rely on interference by previously stored information about the characteristics of the stimuli, the question arises as to what is stored when inhibition succeeded. In previous research, it has been suggested that stopping in the stop signal task, as used in this experiment, is a general, nonspecific way of stopping, canceling all responses and processes (De Jong et al., 1995). In other words, stimuli and their characteristics are not important for the stop; this implicates that the target and distractor do not have to be discriminated from each other. Moreover, since all processes are abruptly cancelled, the processing of the distractor would also be cancelled. Therefore, we suggest that after a successful stop, the episode no longer contains all the stimulus information, such as the specific 'do not respond' tag of the distractor. Since not all information is stored, there is no longer a

conflict of the ignored repetitions and the negative priming effect disappears. Note that when it is assumed that suppression of the distractor never happened, due to the canceling of all responses, the inhibition account could also explain the results. The hypothesis that nonselective stopping causes the disappearance of the negative priming effect is further investigated in Experiment 2.

EXPERIMENT 2

In Experiment 1, stopping performance was not influenced by negative priming, but the negative priming effect disappeared after a successful nonselective stop. In Experiment 2, we further investigated the relation between response inhibition and negative priming by introducing a selective stop, which requires a more cognitively controlled stop. A selective stop task can be based on a perceptual discrimination by using different tones (e.g., only stop when you hear a high tone; e.g., Bedard et al., 2003), or it can be based on a motor discrimination. Logan, Kantowitz, and Riegler (1986), cited by Logan (1994), used this version of the selective stop task. On presentation of the stop signal, participants were required to withhold their response with the right hand but to ignore the signal when the response was to be made by the left hand. Logan et al. (1986) suggested that in this version of the stop task, motor inhibition should be focused on a single response instead of canceling all responses as in the simple stop task. In other words, stimulus characteristics and the discrimination between target and distractor are important for the selective stop process. Based on the memory-based accounts for negative priming, this would imply that after a successful selective stop—contrary to a nonspecific general stop—the stimulus characteristics are stored and later on retrieved. Therefore, a negative priming effect should be found after a successful stop, in contrast with the findings of Experiment 1.

For all these reasons, we used the 'motor version' of selective stopping and combined it with negative priming. The predictions were that selective stopping was not influenced by negative priming, as could be expected from Experiment 1, and that a negative priming effect was observable after

successful selective inhibition due to the extended processing of target and distractor.

METHOD

Participants

Twenty first-year psychology students of Ghent University (Belgium) participated for course requirements and credit. All participants had normal or corrected-to-normal vision and all were naive as to the purpose of the experiment. One participant was excluded from further data analysis because of negative SSRTs, indicating that the participant was waiting for the occurrence of the stop signal.

Signals, tasks and procedure

Apparatus, signals, and the primary task were the same as in the first experiment. Only the changes compared with Experiment 1 will be mentioned. There were two types of stop signals: Valid and invalid signals. The validity of the stop signal was determined by the response to be given to the target stimulus. One half of the participants had to stop when they heard the tone and when their response was pressing one of the index fingers (i.e., the two lower buttons, corresponding to the letters 'F' and 'H'). These were the valid stop signals. When these participants heard a tone and the response was pressing one of the middle fingers (corresponding to the letters 'L' and 'T'), they had to ignore the tone (the invalid stop signal). The other half of the participants had the complimentary mapping of signal validity to fingers. Therefore, the validity of the stop signals was changed between participants, but not within. The experiment started with one practice block and there were 11 experimental blocks. Each block consisted of 56 prime/probe pairs. In a pseudo-random selection of the trials, a stop signal was presented. In 32 of the 112 trials (or 28.5%) a tone occurred after stimulus onset. Half of the tones were valid stop signals, the other half were invalid stop signals. This resulted in 88 signal prime trials (44 valid and 44 invalid) followed by a control probe, 88 signal trials (44 valid and 44 invalid)

followed by an ignored repetition, 44 valid stop signals on a control probe, 44 invalid stop signals on a control probe and finally, 44 valid and 44 invalid stop signals on an ignored repetition. Stop latency was estimated in the same way as in Experiment 1. After the presentation of a valid stop signal, the SSD was adjusted. For invalid stop signals, we used the same SSD we would use for valid stop signals for that specific type of trial. After an invalid stop signal, the SSD was not adjusted. Therefore, the SSD of invalid stop signals was also variable, but the changes were determined by the valid stop signals.

RESULTS AND DISCUSSION

The analyses were the same as in Experiment 1. Participants were very good at ignoring the invalid stop signals (the amount of false alarms, i.e., stop when they had to react, was very low: 6.6% of the trials with an invalid stop signal) and made few errors (mean: 3.6%). Therefore, these data were not further analyzed.

No-signal trials

Besides the three types of no-signal probe trials of Experiment 1 (no-signal, signal-respond, and signal-inhibit), in this experiment there was a fourth type: An invalid stop signal was presented in the prime trial and participants had to respond. The analysis was based on a 2 (probe: Control vs. ignored repetition) \times 4 (signal property of the prime: No-signal, invalid-stop, signal-respond, signal-inhibit) repeated measures ANOVA (lowest p value of the sphericity test was $p = .06$). Results of the no-signal probe trials are presented in Table 4.3. Analyses revealed a main negative priming effect. Participants responded slower on ignored repetitions than on the control probes, $F(1,18) = 24.17$, $p < .001$. We found no main effect of the type of prime trial and the interaction between both main effects was also not significant, both F 's < 1 . One-tailed t -tests revealed a negative priming effect when no signal was presented, $t(18) = -4.36$, $p < .001$, and when an invalid stop signal was presented, $t(18) = -2.48$, $p < .05$. When a valid stop signal was

presented and participants failed to inhibit their response, we found a significant difference between the control probe and the ignored repetition probe, $t(18) = -2.00$, $p < .05$. Most importantly, when the inhibition in valid stop trials succeeded, there was also a reliable negative priming effect, $t(18) = -2.79$, $p < .01$. To investigate whether the presentation of a stop signal delayed the responses in the next trial, we conducted a repeated measures ANOVA for the control probe trials. As in Experiment 1, no general slowing after the presentation of a stop signal was found, $F < 1$.

To summarize, the results of the no-signal probe trials differ from the findings of Experiment 1. The negative priming effect was always present, even after a successful selective stop. This suggests that simple and selective stopping influence differently the negative priming effect.

Table 4.3: Reaction times of no-signal probe trials (SDs in parentheses) as a function of the presentation of a stop signal on the prime trial in Experiment 2. The negative priming effect was computed by subtracting the mean CRT of control probes from the mean CRT of ignored repetitions probes (* $p < .05$; ** $p < .01$).

Priming condition	Prime trial			
	No signal	Invalid signal	Signal-respond	Signal-inhibit
Ignored repetition	764 (70)	769 (83)	772 (95)	756 (110)
Control	740 (73)	750 (84)	750 (100)	734 (108)
Negative priming	24 **	19 *	22 *	22 **

Signal-trials

All analyses of stopping data were repeated measures ANOVAs with probe type (control vs. ignored repetition) as a within-subjects variable. Stopping results are presented in Table 4.4. In spite of the insertion of invalid stop signals, which made the stop task more complicated, the staircase procedure still produced good results. The probability of responding given a stop signal approached the obtained .50 (.46 and .47 for control probes and

ignored repetitions respectively). There was no difference between the probe types, $F < 1$. As commonly observed (see Logan, 1994) and probably due to the higher cognitive demands, the SSRTs of selective stopping were longer than the SSRTs of simple stopping. However, there was again no difference between control probes and ignored repetitions, for SSRTs and SSDs, both $F_s < 1$. This clearly suggests that, like simple stopping, selective stopping is not influenced by negative priming. Finally, CRT data of invalid stop signal probes and signal-respond probes were analyzed separately. Like the comparisons in the primary task, we performed one-tailed t-tests. A negative priming effect was found for both invalid-signal probes and signal-respond probes, $t(18) = -3.40, p < .01$ and $t(18) = -2.01, p < .05$ respectively. These analyses of stopping data are in line with the results of Experiment 1 and suggest that inhibition of responses in the probe trial is not influenced by the distractors of the prime trial.

Table 4.4: SSRTs, probabilities of responding given a stop signal, stop signal delay, signal-respond RT, and RTs of invalid stop trials in Experiment 2 (SDs in parentheses). The negative priming effect was computed by subtracting the mean CRT of control probes from the mean CRT of ignored repetitions probes (* $p < .05$).

	Priming Condition		
	Ignored repetition	Control	Negative priming
Stop signal RT	238 (94)	235 (93)	3
Response ratio (%)	46.0 (6.1)	46.9 (6.0)	- 0.9
Stop signal delay	480 (114)	489 (117)	-9
Signal-respond RT	774 (77)	751 (84)	23 *
Invalid signal RT	761 (121)	731 (110)	30 *

GENERAL DISCUSSION

In the present study, we introduced stop signals in a negative priming design. This allowed us to investigate how negative priming and stop signal inhibition influence each other. Two studies (Kramer et al., 1992; Rieger & Gauggel, 1999) have found after-effects of the behavioural inhibition in the stop signal task and suggested that there could be similarities with the negative priming effect. Negative priming is typically found when two stimuli are presented and the distractor of the prime trial (n) is the target of the probe trial ($n+1$). In the stop signal task, responses are also slowed down when participants have had to suppress a response in the previous trial.

The stopping data of Experiment 1 revealed that stopping performance in the probe trial is not affected by negative priming. SSRTs of control and ignored repetitions did not differ at all, just as no differences between SSDs are found. This finding indicates that the negative priming effect and stopping responses rely on different mechanisms and also contradicts the inhibition account of negative priming. Based on this account, it would be expected that stopping responses should be faster on ignored repetition probes. Due to the residual inhibition, responses on the probe target are already slightly suppressed, which could make the stop signal inhibition faster.

Contrary to the finding that stopping is not influenced by negative priming, the presentation of a stop signal in the prime trial did influence the performance in the probe trial, but only when inhibition succeeded. After a successful inhibition of the response the negative priming effect completely disappeared. Based on the inhibition account, a negative priming effect after a signal-inhibit prime would be expected, since both target and distractor are suppressed when a stop signal was presented and inhibition succeeded. The participants did not know in advance whether a stop signal would be presented in the prime trial and the stop signal was on average presented 500 ms after the stimulus display. Therefore, we assume that participants already discriminated the distractor from the target and started ignoring this distract or, before the stop signal was presented. The fact that we did not

find any effect of the SSD split concerning the negative priming supports this assumption. When it is assumed that stopping a response only has consequences for response execution, the memory-based accounts likewise cannot directly explain the findings. The feature mismatch theory would predict that after the presentation of a stop signal, negative priming would still be present, because there is still a mismatch of the stimuli. It could be argued that due to the absence of the stop signal in the probe trial, the mismatch would be smaller. However, this hypothesis implies that after signal-respond trials, the negative priming effect would also disappear, which was not the case. Secondly, the episodic retrieval account would also expect a conflict at the response level due to the 'do not respond' tag of the prime and the 'do respond' tag of the probe trial. However, the automatic retrieval of previously stored information is crucial in both accounts of negative priming. But simple stopping requires no dissociation between distractor and target or processing of stimulus characteristics. In this version of stopping, all processes and responses are cancelled without further discrimination (e.g., De Jong et al., 1995). This would also imply that the episode no longer contains all information of the distractor, due to the general stop. But without the specific stimulus information, no conflict could arise on ignored repetitions and at the end, no negative priming effects are found.

In Experiment 2, the finding that stopping responses are not influenced by negative priming and the hypothesis that a general nonspecific stop was responsible for the disappearance of the negative priming was further investigated. A selective stop paradigm was introduced, inspired by Logan et al. (1986), who suggested that the selective stop task requires a more specific way of inhibiting the response, in stead of the general stop in simple stopping. Stimulus characteristics are important with this version of the stop task. In contrast to signal-inhibit trials of Experiment 1, the distractor must be identified, resulting in both suppression of the distractor and storage of an episode with specific stimulus information, just as with no-signal trials.

The results of Experiment 2 were straightforward. As in Experiment 1, stopping data clearly demonstrated that the inhibition of motor responses was not affected by negative priming. Therefore, we suggest that the

stopping data of both Experiments 1 and 2 are in favor of the memory-based accounts. After all, the finding that both simple and selective stopping are not influenced by negative priming demonstrates that the mechanism causing negative priming is independent of the mechanisms in the stop signal task. This contradicts the hypothesis of Tipper (Houghton & Tipper, 1994; Tipper & Cranston, 1985) that negative priming is due to a residual inhibition of the link between stimulus and response mechanism.

The second main result of Experiment 2 is that after a successful selective stop the negative priming effect was still present. This finding clearly suggests that the disappearance of the negative priming effect was due to a general nonspecific stop, which not only affects response execution but also affects all task-related processes. This has two main implications. First of all, when stimulus processing is abruptly stopped without full discrimination between distractor and target because such discrimination is irrelevant, negative priming does not occur. This is clearly demonstrated by the difference between simple and selective stopping. In terms of the selective inhibition account, this would mean that the distractor becomes selectively inhibited in a late stage. In terms of the memory-based accounts, this would implicate that stimulus processing must be almost fulfilled before specific stimulus information could be stored. Secondly, the different results in Experiments 1 and 2 are further evidence of at least partially different mechanisms in simple and selective stopping, as previously suggested (Logan, 1994; van den Wildenberg & van der Molen, 2004).

In another paradigm, the backward inhibition paradigm (Mayr & Keele, 2000), similar effects of stopping are found. Mayr and Keele suggested that when participants switched from one task to another, the irrelevant task-set becomes suppressed, which makes the reactivation of the suppressed set in the next trial more difficult. Schuch and Koch (2003) found that after no-go signals with a variant of the stop signal paradigm, the backward inhibition effect disappeared. It is noteworthy that recently MacLeod, Dodd, Sheard, Wilson, and Bibi (2003) suggested a pure memory-based account for backward inhibition and task switching in general (see Monsell, 2003, for a review), similar to the memory-based accounts of negative priming. Like in negative priming, information about previous responses related to the

stimulus is retrieved, causing interference when there is a mismatch. The disappearance of the backward inhibition effect could then be explained in the same way we explained our findings. This also suggests that the findings of the present study could be extended to other paradigms, such as task switching.

Thus, the only after-effect of behavioural inhibition was the disappearance of the negative priming effect in Experiment 1. Unlike Rieger and Gauggel (1999), in neither of the two experiments did we find a general slowing of the responses after a stop signal. Probably, this is due to the presentation of the trials in pairs. It was possible that two signals were presented after each other, but never within one pair. This could influence the strategies of participants. Normally, participants tend to delay their responses in a stop signal task. However, due to the fact that a signal probe trial never followed a signal prime trial, participants could speed up their responses a bit after a signal prime trial. This would explain why we did not find a general slowing down of the responses after the presentation of a stop signal.

To conclude, the results of the present study indicate on the one hand that behavioural inhibition is not influenced by the negative priming effect. We suggest that this is in favor of the memory-based accounts. On the other hand, behavioural inhibition, as operationalized in the simple stop signal task, has an effect on negative priming. This finding is possibly due to the cancellation of all task-related processes, as a result of which the negative priming effect disappeared in the next trial.

CHAPTER 5

STOPPING WHEN SWITCHING: IT DOES MATTER

In the last empirical chapter of this doctoral thesis, the stop signal task is combined with cued task switching. In Chapters 2 and 3, the stop signal experiments revealed something about the nature of selective suppression in different interference or conflict tasks. In Chapter 4, our experiments demonstrated that the negative priming effect disappeared when there was no need to discriminate between distractor and target, whereas response execution seemed not necessary to find a negative priming effect on the next trial.

In the following two studies, we will rely on these latter findings of Chapter 4. We already mentioned in the discussion of the study presented in Chapter 4 that the results obtained with the negative priming paradigm, possibly could be generalized to the task switching paradigm, and this for several reasons. First of all, it was suggested that there might be an overlap between the typically observed switch cost in task switching and the negative priming effect (see e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Furthermore, in a recent paper of Rothermund, Wentura and De Houwer (2005), a new model is presented that explains negative priming in terms of the retrieval of stimulus-response associations. Since a similar explanation is proposed by Wylie and Allport (2000) to explain the switch cost, it seems plausible to assume that our findings with negative priming can indeed be generalized to the task switching paradigm. Secondly, Schuch and Koch (2003) introduced no-go trials in a typical task switching experiment and found that after a no-go trial no switch cost was observed.

Thus, in this chapter, we started from our own findings with the negative priming paradigm and from the Schuch and Koch paper, and looked at the effect of response inhibition on task switching. It was predicted that the switch cost would disappear after a signal-inhibit trial. Secondly, the stop signal task has, compared to the go/no-go paradigm, the advantage of that it allows investigation of the influence of task switching on response inhibition. Results of Friedman and Miyake (2004) suggest a relation

between prepotent response inhibition and task switching. Also, in a review article of Aron, Robbins, and Poldrack (2004) it was suggested that there was a close overlap between task switching and response inhibition, since both functions consistently activates the inferior parietal cortex.

INHIBITING RESPONSES WHEN SWITCHING: DOES IT MATTER?^{19,20}

In the present study, cued task-switching was combined with the stop-signal paradigm in order to investigate the interaction between response inhibition and task-switching. In line with earlier findings from Schuch and Koch (2003), the results show that switch and repetition trials following inhibited responses were processed equally fast. This confirms the hypothesis of Schuch and Koch (2003) that after signal-inhibit trials there is less interference, resulting in a disappearance of the switch cost. Furthermore, stopping performance was not affected by task-switching. The estimated stop-signal latencies were similar for switch and repetition trials, while the stop-signal delays were longer for switch compared to repetition trials. This result suggests that response inhibition and the inhibition processes in cued task-switching are not relying upon a common mechanism.

¹⁹ Verbruggen, F., Liefoghe, B., Szmalec, A., & Vandierendonck, A. (2005). Inhibiting responses when switching: Does it matter? *Experimental Psychology*, 52, 125-130.

²⁰ We would like to thank Iring Koch and Ulrich Mayr for their useful comments on a previous version of this manuscript.

INTRODUCTION

It is a well-replicated finding that switching between tasks is associated with a cost in performance which is indicated by longer latencies and higher error rates. In the last decade, a substantial body of research attempted to clarify this switch-cost by identifying the different component processes and patterns of interference that are present during task-switching (see Monsell, 2003 for a review). Over the years, two main approaches to task-switching can be distinguished. On the one hand, Rogers and Monsell (1995) suggested that switch-costs reflect an active reconfiguration of the parameters associated with each task (i.e., the task-set). Switching would take more time compared to repetition because it involves the additional process of changing the task-set. On the other hand, Allport, Styles, and Hsieh (1994) proposed that the switch-cost reflects a kind of proactive interference from one trial to another. Within this account, a switch trial is harder because some residual activation from a previous trial, involving a different task, causes carryover effects. Later on, Wylie and Allport (2000) suggested that during task-switching stimulus-response associations are constantly modified. When a stimulus is presented, previous response related information of that stimulus is retrieved. In case of inconsistent information, there is interference that slows down the response selection.

Recently, a number of attempts have been made to integrate task-switching within the broader framework of working memory. Within this vein, a fruitful proposal was made by Mayr (Mayr and Keele, 2000; Mayr and Kliegl, 2000). It was suggested that, when switching from one task to another, the irrelevant task-set must be inhibited or even displaced from working memory and the alternative task-set must be retrieved from long-term memory. This position was refined by Schuch and Koch (2003) who presented compelling evidence that the suppression of the irrelevant task-set takes place in the response selection stage. They combined cued task-switching with a go/no-go paradigm. On 25% of the trials (the *no-go* trials), a low tone was presented simultaneously with the stimulus indicating that participants did not have to react to that stimulus. Schuch and Koch (2003)

found that switch and repetition trials were processed equally fast when they followed no-go trials. In a subsequent experiment, they demonstrated that response selection and not response execution was the mediating factor. Therefore, Schuch and Koch (2003) explained those results by suggesting that after a no-go trial less residual activation interfered with the upcoming response selection. They consider response selection as a modifying agent during task-switching: When a response selection is made, the relevant response selection rules are activated and the irrelevant response translation rules are inhibited. This implies that the rules that were relevant on the previous trial are activated to some degree until the next response selection is done. Note that these ideas of Schuch and Koch (2003) are consistent with the proposals of Wylie and Allport (2000) since they all stress the fact that at least part of the switch cost is due to interference of the previous trial(s).

The aim of the present study is to further investigate the account of Schuch and Koch (2003) by extending their results with another inhibitory task: The stop signal task. Instead of fixed go/no-go signals, variable stop-signals are used in order to explore the nature of the inhibitory process that Schuch and Koch (2003) assume to be present in task-switching.

In the stop-signal paradigm, participants usually have to execute a speeded choice reaction time task (Lappin & Eriksen, 1966; Logan, 1994; Logan & Cowan, 1984). Occasionally, a stop-signal is presented. The stop-signal tells the participants to suppress their response. On short stop-signal delays (SSD; the interval between the presentation of the go signal and the stop-signal), participants can easily suppress their response. By contrast, when the stop-signal delay is long enough, participants will nearly always execute the response. Therefore, the important difference with go/no-go paradigms, like the one used by Schuch and Koch (2003), lays in the fact that the stop-signal is always presented after the stimulus onset and with a variable delay.

To explain the results found with the stop-signal paradigm, Logan and Cowan (1984) propose a race between two processes: A go process and a stop process. According to their horse-race model, if the stop process is completed before the go process, participants will inhibit their response (signal-inhibit trials). On the contrary, when the go process finishes before

the stop-process, participants will respond (signal-respond trials). Based on the assumptions of the horse-race model, it is possible to estimate the covert latency of stopping: The Stop-Signal Reaction Time (SSRT). The stop-signal paradigm has been used with different response modalities and different populations, and it is clear that it provides a useful instrument for measuring behavioural inhibition (for reviews see Logan, 1994, and Band, van der Molen & Logan, 2003).

Moreover, the combination of the stop-signal task with other paradigms has shown to be promising for investigation of the relation between different kinds of inhibition. On the one hand, Logan (1981) found that stopping spatially incompatible responses did not differ from suppressing spatially compatible responses. This finding led to the conclusion that resolving interference of spatially incompatible responses (Kornblum, Hasbroucq & Osman, 1990) and stopping of behaviour do not interact. On the other hand, several authors found that stopping motor responses was influenced by distracting information in flanker and Stroop tasks (e.g., Ridderinkhof, Band, & Logan, 1999; Verbruggen, Liefoghe, & Vandierendonck, 2004), indicating that there are common mechanisms in the suppression of the distractors in conflict tasks and response inhibition. This conclusion is based on the assumption that an interaction, indicated by longer stopping latencies, suggests a common mechanism, while additive effects should be found when the stop-signal task and the inquired paradigm call upon different resources. Therefore, in the present study we will also investigate whether the inhibitory process involved in cued task-switching is relying upon the same construct as response inhibition.

In summary, the present study aims to replicate the results of Schuch and Koch (2003) with a different inhibitory task, the stop-signal task, which can provide us some insights about the origin of the switch cost and the nature of the inhibitory process involved in cued task-switching.

EXPERIMENT

METHOD

Participants

Twenty-five undergraduate students in Psychology at Ghent University participated for course requirements and credit. All participants had normal or corrected-to-normal vision, were right-handed, and all were naive as to the purpose of the experiment. One participant was excluded from further data-analysis because of an error percentage of 32%.

Materials

The experiment was run on a Pentium PC. Stimuli were presented on a 17-inch monitor, placed at a distance of 50 cm in front of the participants. In the centre of the screen a white 2 by 2 grid (approximately $4^\circ \times 4^\circ$) was present during the entire experiment. On each trial a white circle with a radius of 1° was presented in the grid and participants had to decide whether it was located in the upper or lower part of the grid for the first task and if it was on the left or the right for the second task. For responding, both tasks were mapped onto the '7' and '3' keys of the numeric keypad. Depending on the task '7' meant up or left, while '3' meant down or right. The up-down task was indicated by two vertically opposing arrows (1.3° in length and 0.4° in height) and two horizontally opposing arrows indicated the left-right task. Occasionally a loud and clear auditory stop-signal (750 Hz, 70dB, 50 ms) was presented shortly after the stimulus onset in the visual primary task.

Procedure

The participants were tested individually. One block of 80 practice trials was followed by 8 blocks of 80 test trials with a small break after each block. Each trial started with the relevant arrows being displayed until the

response was given. A fore period of 300 ms elapsed and the circle was presented and required a response within 2,000 ms after its onset. When a response was given, the target disappeared and the 1,250 ms inter-trial interval started. On a pseudo-random selection of 25% of the trials, a stop-signal was presented. This resulted in 80 repetition stop trials and 80 switch stop trials. The stop-signal delay was initially set at 250 ms and was continuously adjusted according to a staircase tracking algorithm (Levitt, 1970) for each type of trial to obtain a probability of stopping of 50%. This method provides SSRT estimations that are derived from the central part of the no-signal RT distribution curve. Logan, Schachar and Tannock (1997; see also Band et al., 2003) demonstrated that 'central' estimates are relatively insensitive to violations of the horse-race model and therefore most reliable. In order to obtain an approximate probability of 50%, each time the subject responded to the stimulus in the presence of a stop-signal, the stop-signal delay decreased with 50 ms. Conversely, after a successful inhibition, the delay increased with 50 ms. In order to avoid 'waiting' strategies, participants were informed about the tracking procedure and about the fact that the probability of stopping will approximate 50%, irrespective of whether they were postponing their response or not. At the end of each block, feedback about their mean performance was presented: The mean CRT of no-signal trials and the percentage of suppressed trials.

Stop latency estimation

SSRTs were estimated as proposed by Logan and Cowan (1984), based on the horse-race model. According to this model, after rank ordering the CRTs of no-signal trials, the left, fast part of this CRT-distribution is assumed to correspond to the distribution of CRTs of signal trials on which inhibition failed. The finishing time of the stop process corresponds to the n th CRT of the no-signal trials, where n is the result of multiplying the total number of no-signal trials by the probability of responding when a signal is presented, given a certain SSD. As the start of the inhibition process (mean SSD) and the finishing time are known, the SSRT can be estimated. The SSRT

is the result of the subtraction 'finishing time minus start' or 'nth CRT minus SSD' (see Logan, 1994).

RESULTS

CRT and error data were subjected to a within-participant trimming procedure. Mean CRTs of correct trials and error percentages were calculated after removal of outlying CRTs; i.e., CRTs longer than 2 standard deviations above the mean were discarded from data analysis. This resulted in a data reduction of 4.6%. Since switch trials are expected to be slower, all post hoc tests were one-tailed t-tests.

No-signal trials

The means of no-signal trials are presented in Table 5.1. We conducted a 2 x 3 repeated measures ANOVA (p -value sphericity = .23), with properties of trial n (repetition vs. switch) and signal properties of trial $n-1$ (no-signal, signal-respond, signal-inhibit) as within-subjects variables. Repetition trials were generally faster than switch trials, $F(1,23) = 13.72, p < .01$, and there was also a main effect of trial $n-1$, $F(2,46) = 14.06, p < .001$. The interaction between both main effects was also significant, $F(2,46) = 3.34, p < .05$. Next, one-tailed t-tests showed that a switch cost was found when no signal was presented or when the inhibition failed the previous trial, $t(23) = -3.41, p < .001$ and $t(23) = -2.50, p < .01$, respectively. On the contrary, when inhibition succeeded, there was no longer a switch cost, $t(23) = 0.23, p = .41$.

Error analysis revealed no significant effect of the previous trial, $F < 1$. There was only a marginal significant switch cost, $F(1,23) = 3.54, p = .07$. However, the interaction was significant, $F(2,46) = 4.97, p < .05$. One-tailed t-tests revealed a switch cost after no-signal trials, $t(23) = -3.72, p < .001$, and after signal-respond trials, $t(23) = -2.23, p < .05$. Like in the CRT-analysis, no switch cost was found after signal-inhibit trials, $t(23) = 1.21, p = .12$.

Table 5.1: Reaction times and error percentages of no-signal trials (SDs in parentheses) as a function of the presentation of a stop-signal on the previous trial.

Trial n	Trial n-1					
	No-signal		Signal-inhibit		Signal-respond	
	CRT	Errors	CRT	Errors	CRT	Errors
Repetition	465 (88)	4.4 (3.7)	486 (102)	6.2 (8.1)	509 (110)	4.8 (5.8)
Switch	498 (126)	6.5 (5.5)	484 (107)	4.9 (6.6)	535 (115)	6.5 (6.7)
Switch Cost	33	2.1	-2	-1.2	26	1.7

Signal trials

All analyses are repeated measures ANOVAs with ‘repetition vs. switch’ as within-subjects variable. The probabilities of responding given a stop-signal approached the obtained .50 (.51 for repetition trials and .50 for switch trials, $F(1,23) = 5.1, p < .05$). As can be seen in Table 5.2, the mean SSD of repetition trials was significantly lower than the SSD of switch trials, $F(1,23) = 4.99, p < .05$. On the contrary, the SSRTs did not differ, $F < 1$. Finally, when the participant responded in spite of a stop-signal, again a switch cost was found, $F(1,23) = 4.58, p < .05$.

Table 5.2: SSRTs, probabilities of responding given a stop-signal, stop-signal delay, and signal-respond RT (SDs in parentheses).

	Priming Condition	
	Repetition	Switch
Stop-signal RT	207 (74)	206 (83)
Response ratio (%)	51.4 (3.8)	50.3 (3.2)
Stop-signal delay	253 (60)	273 (76)
Signal-respond RT	419 (82)	442 (102)

DISCUSSION

The present study aimed to further investigate the account of Schuch and Koch (2003) by replicating their findings with different tasks. In analogy with previous research, our results confirm that switch and repetition trials subsequent to successfully inhibited responses are processed equally fast. This result generalizes the findings of Schuch and Koch (2003) since we combined a different cueing paradigm with another inhibitory task, the stop-signal task, suggesting that when there is no interference due to the previous trial, the switch cost disappears. However, an alternative explanation for the findings of Schuch and Koch (2003) and possibly for the present results has been made by Kleinsorge and Gajewski (2004). They suggested that participants are less willing to engage in advance task-set reconfiguration, which results in the disappearance of the switch cost. But contrary to the studies of both Schuch and Koch (2003) and Kleinsorge and Gajewski (2004) where a no-go paradigm was used, the use of a stop signal paradigm allows to investigate what happens after signal-respond trials. Based on the motivational explanation of Kleinsorge and Gajewski (2004), one would expect that after signal-respond trials no switch cost is observable, especially since the inhibition failed. However, the analysis clearly showed that notwithstanding participants responded slower on signal-respond trials, a switch cost was still observable. Therefore, we suggest that the motivational account of Kleinsorge and Gajewski (2004) cannot explain the present data pattern.

The use of the stop signal paradigm has also another implication, since the crucial manipulation was not restricted to the response selection stage, compared to Schuch and Koch (2003). After all, in the stop signal paradigm, responses can be inhibited even after the response selection has been made, as demonstrated by electrophysiological measures such as the lateralized readiness potential and electromyogram (De Jong, Coles, & Logan, 1995). Therefore, we suggest that response inhibition directly influences the activation of the stimulus-response rules. When the inhibition succeeds, the activation level of the stimulus response rules drops, with as a result a

disappearance of the switch cost because of a lower level of interference at the time of response selection of the next trial.

The present finding also converges with the results of a recent study on negative priming by Verbruggen, Liefvooghe, and Vandierendonck (2005b). It was found that response inhibition on prime trials did abolish the ignored repetition effect on the probe trials. In case of no-signal primes or signal-respond primes, a negative priming effect was found on the probe trial. The authors suggested that response inhibition in its simplest form cancels all processing, as a result of which no negative priming is found after a successful stop.

A further important result of the present experiment is the observed additivity between task-switching and response inhibition. First of all, the SSRTs of repetition trials and switch trials are almost equal, which suggests that the ease of response inhibition is the same for both types of trials. Secondly, the SSDs differ significantly from each other. Based on the assumptions of the horse race model, this SSD difference is also evidence for the independence of two mechanisms. After all, the tracking procedure used in the present experiment takes both inter-individual and intra-individual differences and also task difficulties into account. When two tasks, or in this experiment two types of trials (repetition vs. switch trials), differ from each other, the normally distributed CRT curves of no-signal trials are not completely overlapping. The curve of the more difficult task is situated more to the right. In relation to the stop process, this would imply that the SSD of the more difficult task is longer (see Logan, 1994, for an extensive discussion of this issue), provided that stopping performance and the primary task do not call upon the same mechanisms or are functionally independent. Note that functional dependency does not undermine the assumptions of the horse race model (see the simulations of Band et al., 2003). Taken together, the equal signal-respond ratios, equal SSRTs but different SSDs, suggest an additivity of processes involved in task-switching and stop-signal inhibition. In conclusion, response inhibition and the inhibitory processes involved in task-switching do not seem to rely upon a common mechanism.

Although this interaction was never directly tested, the present additivity is not surprising. Mayr and Keele (2000, p. 22) suggested that the

inhibitory process involved in task-switching may be 'relatively impenetrable for higher-level control' and prefer the notion of some lateral inhibition above the concept of a more active form of self inhibition. In a similar vein, results of Hübner, Dreisbach, Haider and Kluwe (2003) are in favour of an automatically triggered kind of inhibition again in analogy with the concept of lateral inhibition. However, the stop signal task is only found to interact with other inhibitory tasks that require active suppression of responses such as the antisaccade task (Logan & Irwin, 2000) and the flanker and Stroop task (Ridderinkhof et al., 1999; Verbruggen et al., 2004). Therefore, it seems reasonable that the presumed lateral inhibition in task switching does not interact with response inhibition. In summary, the present results offer some indirect additional evidence that the inhibitory process involved in task-switching is quite automatic and lateral in nature, although we cannot exclude an active form of inhibition. There are also reasons to believe that the found additivity is specific to the cued task switching paradigm that was used in the present study. First of all, we used a task where the relation between stimulus and response is very straightforward (e.g., Lu & Proctor, 2001). This implies that the demands on response selection and the related functions, such as inhibition, are probably restricted. The short latencies and small switch costs are in support for this hypothesis. Secondly, there is evidence from neuroimaging and lesion studies that both response inhibition and task switching consistently activates the inferior parietal cortex (Aron, Robbins, & Poldrack, 2004), suggesting a close functional overlap between both functions. Therefore, it is possible that by using tasks with higher demands on response selection or by using three tasks like in a backward inhibition paradigm (e.g., Mayr and Keele, 2000), response inhibition will be influenced by task switching.

Taken together, the present study offers a twofold extension of Schuch and Koch's (2003) results. Firstly, the present results show that the activation ratio between the different response rules is important during task-switching. Response inhibition modifies this ratio which leads to equal performances on subsequent switch and repetition trials. Secondly, there seems no common mechanism underlying response inhibition and inhibition in task-switching. Further research is however needed to clarify the

relationship between response inhibition and task switching in order to generalize the present findings.

**SELECTIVE STOPPING IN TASK SWITCHING:
THE ROLE OF RESPONSE SELECTION AND
RESPONSE EXECUTION^{21,22}**

Recently, several studies stressed the role of response selection in cued task switching. The present study tried to investigate directly the hypothesis that no switch cost can be found when there was no response selection. In two experiments, we combined a cued task switching paradigm with the selective stopping paradigm. Results of the experiments demonstrated that a switch cost was found when participants selected a response, even without response execution. Alternatively, when the response was inhibited without the need of response selection, no switch cost was found. These results provide direct evidence for the distinct role of response selection in cued task switching and suggest that response execution is not a necessary factor to obtain a switch cost.

²¹ Verbruggen, F., Liefoghe, B., & Vandierendonck, A. (in press). Selective stopping in task switching: The role of response selection and response execution. *Experimental Psychology*.

²² We would like to thank Thomas Kleinsorge and Ulrich Mayr for their useful comments on a previous version of this manuscript.

INTRODUCTION

It is a common finding that switching between two different tasks is associated with a cost in reaction times and accuracy (see Morsel, 2003, for a review). Different proposals have been made to explain this switch cost and it seems that at least two different kinds of processes contribute to the switch cost. Firstly, each task is assumed to be associated with internal constraints (i.e., the task set), enabling a correct performance of the task. Switching would take more time compared to repetition because it involves the additional active reconfiguration process of changing the task set (e.g., Rogers & Monsell, 1995). Secondly, Allport suggested that at least part of the switch cost is due to carry-over effects of the previous trial (Allport, Styles, & Hsieh, 1994). Later on, Wylie (Wylie & Allport, 2000; Wylie, Javitt, Fox, 2004) hypothesized that the retrieval of previous stimulus-response associations causes between-task interference on the current trial due to the response requirements of the task. This between-task interference delays the responding on the current trial and explains why there is still a switch cost present even when participants have sufficient time to prepare the task before the stimuli are presented.

Recently, also much interest has arisen in the role of response selection in the establishment of the switch cost. The first study that directly addressed the role of response selection in task switching was the paper of Schuch and Koch (2003). These authors suggested that in task switching there are overlapping stimulus-response rules of the different tasks. However, at the stage of response selection the irrelevant stimulus-response rules are inhibited. This inhibition of the task set is still observable on the next trial, causing a delay when participants have to switch to the task that was previously inhibited.

Schuch and Koch (2003) demonstrated the importance of response selection by integrating a go/no-go task with the cued task switching paradigm and the backward inhibition paradigm. They found that both the switch cost and the backward inhibition effect were absent after a no-go trial and suggested that this resulted from the absence of a response selection in a

no-go trial. No response selection means also that there is no application of the relevant task set. For that reason, there was also no inhibition of the irrelevant task set. In other words, there is no residual inhibition after a no-go trial. Later on, Verbruggen, Liefoghe, Szmalec and Vandierendonck (2005a) replicated this finding with the simple stop signal task (see Logan, 1994, for a review). Unlike a go/no-go task, the stop signal is always presented after the stimulus presentation. Basically, these authors found the same results as Schuch and Koch (2003). When participants could correctly inhibit their response on the previous trial (*signal-inhibit trial*), no switch cost was found. However, when participants responded in spite of a stop signal (*signal-respond trial*), there was still a switch cost. Verbruggen et al. (2005a) also suggested that these results are in favor of an account that stresses the role of response selection in task switching.

However, contrary to the explanation of Schuch and Koch (2003), Kleinsorge and Gajewski (2004) hypothesized that participants were less willing to engage in advance task set reconfiguration when occasionally no-go trials were presented. Furthermore, they suggested that this lack of advanced preparation resulted in the disappearance of the switch cost. Although it is not exactly clear what can be expected after a signal-respond trial based on the motivational account of Kleinsorge and Gajewski (2004), one could assume that there would be no difference between trials that followed a signal-respond trial compared to trials that followed a signal-inhibit trial. In both types of trials, there was a stop signal presented and Kleinsorge and Gajewski (2004) argued that the motivational aspect was context (or block) based. Thus, the important difference is that in signal-respond trials, the inhibition failed and participants responded whereas on signal-inhibit trials there was no response. Therefore, Verbruggen et al. (2005a) suggested that their results obtained with the stop signal task were best explained by the hypothesis that response selection, or task set application, is an important and mediating factor in task switching.

In the present study, we wanted to further investigate the hypothesis that response selection and task set application is indeed a mediating factor in task switching, by means of two different selective stop signal tasks. Verbruggen et al. (2005a) used a simple stop task in which all responses had

to be inhibited when an auditory stop signal occurred. However, a selective stop task requires that the stop is controlled. A selective stop task can be based on a perceptual discrimination by using different tones (e.g., only stop when you hear a high tone; e.g., Bedard et al., 2003), or it can be based on a motor discrimination. Logan, Kantowitz and Riegler (1986), cited by Logan (1994), used this motor version of the selective stop task. On presentation of the stop signal, participants were required to withhold their response with the right hand but to ignore the signal when the response was to be made by the left hand. Logan et al. (1986) suggested that in this version of the stop task, motor inhibition should be focused on a single response instead of cancelling all responses as in the simple stop task. Unlike the perceptual variant of the selective stop signal task, the motor variant of the selective stop task implies a response selection in the primary task before the response inhibition since only half of the responses (e.g., only left-handed responses) should be inhibited.

For an investigation of the mediating role of response selection, the present study used cued task switching combined with selective stopping based on the response selection of the primary task in Experiment 1 and with selective stopping based on a perceptual discrimination in Experiment 2. This procedure has two important advantages in comparison with previous studies. First of all, Schuch and Koch (2003) found a general increase of choice reaction times (CRTs) after a no-go trial and suggested that this increase was due to a switch from a no-go trial to a go trial. Only when this switch was made (i.e., deciding whether they had to respond or inhibit), participants would proceed processing the stimulus and the appropriate response. But this implied, as they pointed out (Schuch & Koch, 2003, p.96), that the go/no-go switch and the task switch should have additive effects in order to preserve their hypothesis that the absence of response selection in a no-go trial caused the disappearance of the switch cost on the next trial. By using the different forms of selective stopping, we avoided this problem since after different forms of stopping the same switch had to be made. Secondly, in both the studies of Schuch and Koch (2003) and Verbruggen et al. (2005a) response selection and response execution were confounded in the sense that the absence of response selection was always

associated with an absence of response execution. Schuch and Koch (2003) tackled this problem indirectly in their Experiment 3 and 4 by demonstrating that response execution without response selection did not cause a switch cost on the next trial. However, one could argue that their manipulation ('tap both response buttons') influenced also other processes besides response selection.

In Experiment 1 of the present study, there was a direct test of the suggestion that response selection without response execution is a sufficient factor in the establishment of the switch cost. If the response selection hypothesis is correct, one would expect a switch cost after a correctly inhibited trial in the selective stop signal task based on response selection. In order to be sure that participants could not base their decision about the validity of the stop signal on stimulus features, we used eight different digits in two different tasks: A parity task and a magnitude task. We predicted that in Experiment 1 a switch cost should be present after a correctly inhibited trial (i.e., a *signal-inhibit trial*) when response selection in the primary task is a mediating factor in the establishment of the switch cost on the next trial.

EXPERIMENT 1

METHOD

Participants

Twenty first-year psychology students (18 females and 2 males) at Ghent University (Belgium) participated for course requirements and credits. All participants had normal or corrected-to-normal vision, were right-handed, and all were naive as to the purpose of the experiment.

Materials

The experiment was run on a Pentium 4 PC running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press) and the stimuli were presented on a 17-inch monitor. We used the digits 1-9 (0.6 x 0.3 cm), excluding 5. The white digits always appeared in the centre of the screen on

a black background (see Figure 5.1). The task cues were presented on the left and the right of the digit. The letters 'On' (for 'oneven', meaning odd) and 'Ev' (for 'even', meaning even) indicated the parity task; the letters 'Kl' (for 'kleiner', meaning smaller) and 'Gr' (for 'groter', meaning larger) indicated the magnitude task. The position of the cues always corresponded to the relevant response mapping. For example, 'On' was always presented on the left of the digit whereas 'Ev' was always presented on the right of the digit. Responses were collected via a response box connected to the parallel port of the PC. Occasionally (one third of the trials), an auditory stop signal (750Hz, 50 dB, 75 ms) was presented through closed headphones (Sennheiser HD 265-1) shortly after the stimulus onset in the primary task. The validity of the stop signal was presented at the center of the top and bottom of the screen. For example, when participants had to stop their responses with the left hand and ignore the stop signal in case of right-handed responses, we presented 'LEFT = STOP' in Dutch ('LINKS = STOPPEN') at the top and bottom of the screen (see Figure 5.1). This information remained on the screen during the whole experiment.

Task and procedure

There were two different tasks and the same two response buttons were used for both tasks. In the parity task, odd was mapped on the index finger of the left hand and even was mapped on the index finger of the right hand. 'Smaller than five' was mapped on the left finger and 'larger than five' was mapped on the right finger. The validity of the stop signal was dependent on the response hand. One half of the participants had to ignore the stop signal when the response was with the right hand and had to inhibit left handed responses. This mapping was reversed for the other half of the participants. Each trial started with the presentation of the task cue. After 300 ms, the digit appeared in the middle of the screen and required a response within 2,000 ms in case of no-signal trials or invalid signal trials. Both the cue and the stimulus remained on the screen until the response was given, after which the trial ended. When a valid stop signal was presented,

the trial ended after 1,500 ms unless participants had responded. The intertrial interval was 1,250 ms.

Participants received oral instructions. The experiment consisted of one practice phase and one experimental phase. Firstly, there was one practice block of 20 trials without stop signals. In a second practice block of 48 trials, stop signals could occur. During the practice phase, participants received immediate feedback. The word 'FOUT' (meaning *wrong*) appeared in the centre of the screen for 500 ms when participants made an error. When participants incorrectly suppressed a response on an invalid stop signal, the word 'REAGEER' (meaning *react*) was presented. Finally, when the inhibition failed, the word 'STOP' appeared. The experimental phase consisted of eight blocks of 96 trials. On a random selection of one third of the trials, a stop signal was presented. Half of the stop signals was valid, half of the stop signals was invalid. This resulted in 64 valid and 64 invalid stop signals for repetition trials and 64 valid and 64 invalid stop trials for the switch trials. During the experiment, participants received feedback at the end of each block only: The number of errors made during the block, the mean reaction times (CRT), the amount of false alarms (i.e., no response when an invalid stop signal was presented) and the mean probability of stopping were presented.

The stop signal delay was initially set at 250 ms and continuously adjusted according to separately staircase tracking procedures for repetition and switch trials to obtain a probability of stopping of .50. In order to avoid 'waiting' strategies, participants were informed about the tracking procedure and about the fact that the probability of stopping will approximate 50%, irrespective of whether they were postponing their response or not. Each time a participant responded to the stimulus in the presence of a valid stop signal, the stop signal delay decreased with 50 ms. When inhibition succeeded after a valid stop signal, the stop signal delay increased with 50 ms. After an invalid stop signal, the stop signal delay was not adjusted. Based on the assumptions of the horse-race model, SSRT can be calculated by simply subtracting '*mean SSD*' from '*mean CRT*' (Logan, 1994).



Figure 5.1: Example of the display of the screen during the experiment.

RESULTS

CRT data were subjected to a within-participant trimming procedure. Mean CRTs of correct trials were calculated after removal of outlying CRTs (3 standard deviations above the mean). This resulted in a data reduction of 0.8%. Since there were few false alarms (1.6%; i.e., no response when an invalid stop signal was presented), these data were not further analyzed. All reported F-values are approximations to Wilks' lambda.

No-signal data

No-signal data are presented in Table 5.3. CRTs were analyzed by means of a 2 (trial n : Repetition vs. switch) by 4 (trial $n-1$: No-signal, invalid signal, signal-respond, signal-inhibit) repeated measures MANOVA. Firstly,

for CRTs there was a general switch cost on trial n , $F(1,19) = 67.28$, $p < .001$. The signal properties of trial $n-1$ also affected the CRTs on the trial n , $F(3,17) = 76.40$, $p < .001$. Both main effects interacted significantly, $F(3,17) = 39.64$, $p < .001$. Secondly, two-tailed t-tests were performed as a function of the signal properties of trial $n-1$. After all types of trials, we found a switch cost. There was a switch cost after a no-signal trial, $t(19) = -3.85$, $p < .005$, or when an invalid stop signal was presented on trial $n-1$, $t(19) = -11.74$, $p < .001$. We found also a switch cost when after both a signal-respond trial, $t(19) = -5.17$, $p < .001$, and after a signal-inhibit trial, $t(19) = -7.05$, $p < .001$.

A similar pattern was observed for the error data. A 2 (trial n : Repetition vs. switch) by 4 (trial $n-1$: No-signal, invalid signal, signal-respond, signal-inhibit) repeated measures MANOVA revealed a main effect of trial n , $F(1,19) = 24.94$, $p < .001$, and trial $n-1$, $F(3,17) = 168.6$, $p < .001$. The interaction was also significant, $F(3,17) = 4.48$, $p < .05$. A switch cost was observed after a no-signal trial, $t(19) = -3.50$, $p < .005$, and after a signal-inhibit trial, $t(19) = -4.30$, $p < .001$. However, after an invalid stop signal and after a signal-respond trial, the switch cost disappeared, $t(19) = 1.12$, $p = .23$ and $t(19) = -1.11$, $p = .28$, respectively.

Table 5.3: Choice reaction times (CRT) and error percentages (E%) in Experiment 1 (SDs in parentheses) of repetition trials and switch trials as a function of the signal properties of trial $n-1$. The switch cost was computed by subtraction the means of repetition trials of the means of the switch trials (* $p < .005$; ** $p < .001$).

	Trial n-1							
	No-signal		Invalid signal		Signal-respond		Signal-inhibit	
	CRT	E%	CRT	E%	CRT	E%	CRT	E%
Repetition trial	717 (119)	2.8 (1.8)	760 (31)	4.8 (0.8)	812 (36)	4.4 (1.4)	852 (52)	2.1 (1.0)
Switch trial	754 (144)	4.6 (2.6)	836 (50)	4.3 (1.5)	888 (81)	5.1 (1.4)	868 (52)	3.0 (0.5)
Switch cost	37*	1.8*	76**	-0.5	76**	0.7	16**	0.9**

Signal-data

Although the stop signal inhibition was complex, the staircase tracking procedure still produced relatively good results (probability of responding given a stop signal was .47). Thus, SSRTs could be reliably estimated. As can be seen in Table 5.4, response inhibition in the selective stop task was influenced by task switching, indicated by longer SSRTs for switch trials than for repetition trials, $t(19) = -6.17, p < .001$. When a stop signal was presented but participants responded (i.e., valid signal-respond trials), a switch cost was observed, $t(19) = -4.96, p < .001$. Also, when an invalid stop signal was presented and participants correctly ignored the signal (i.e., invalid stop trials), there was also a switch cost, $t(19) = -3.81, p < .005$.

Table 5.4: Stop signal reaction times (SSRT), signal-respond RTs (V-SRT) and RTs of invalid stop trials (IV-SRT) in Experiment 1 (SDs in parentheses; * $p < .005$; ** $p < .001$).

	SSRT	V-SRT	IV-SRT
Repetition trial	254 (107)	694 (131)	656 (118)
Switch trial	303 (108)	761 (158)	725 (155)
Switch cost	49**	67**	69*

DISCUSSION

In Experiment 1, we hypothesized that if response selection is indeed the mediating factor in task switching, as suggested by Schuch and Koch (2003), a switch cost should be present, after a signal-inhibit trial since participants had to make a response selection before they knew the validity of the stop signal. The results of Experiment 1 provided direct evidence for this hypothesis since the switch cost was present after all types of trials, even after a correctly inhibited response. Although this cost was smaller, it was still significant. This finding clearly indicates that response selection is a

mediating, sufficient factor in task switching, without the execution of the response.

A second important finding is that response inhibition in the selective stop task and task switching do interact. This is different from the findings with the simple stop task. Verbruggen et al. (2005a) found that the SSRTs of switch trials were comparable to the SSRTs of repetition trials. However, in Experiment 1, they did differ significantly. We will get round to this finding in the general discussion.

EXPERIMENT 2

In Experiment 1, a switch cost was observed when the inhibition on the previous trial succeeded. In other words, there was no response execution on the previous trial. We argued that this finding was due to the fact that participants had to make a response selection before they knew whether they had to stop or not. However, another possibility would be that the different findings in Experiment 1 and the study of Verbruggen et al. (2005a) are due to the more complex form of selective stopping – in comparison with simple stopping – in Experiment 1, unrelated to the response selection. Therefore, in Experiment 2, cued task switching was combined with a selective stopping based on a perceptual discrimination by using different tones (e.g., Bedard et al., 2003). This form of selective stopping does not require a response selection in the primary task. If the findings of Experiment 1 were indeed due to the response selection in the selective stop task, no switch cost should be present after a signal-inhibit trial in case of selective stopping based on a perceptual discrimination.

METHOD

Participants

Nineteen first-year psychology students (17 females and 2 males) at Ghent University (Belgium) participated for course requirements and credits. None of the participants participated in Experiment 1. All

participants had normal or corrected-to-normal vision, were right-handed, and all were naive as to the purpose of the experiment.

Materials, task and procedure

The only difference in comparison with Experiment 1 is related to the stop signals. The validity of the stop signal was no longer dependent on the response hand. Instead, we used a perceptual variant of the selective stop signal task; i.e., the pitch of a tone determined whether participants had to stop or not. One half of the participants had to ignore a low tone (250Hz) and suppress their response when a high tone (750Hz) occurred. This mapping was reversed for the other half of the participants. Information about the validity remained on the screen during the experiment. For example, when a high pitched stop signal was valid, 'HIGH = STOP' was presented in Dutch ('HOOG = STOPPEN') at the top and bottom of the screen. There were no other changes in comparison with Experiment 1.

RESULTS

We used the same trimming procedure as in Experiment 1. This resulted in a data-loss of 1.6%. The percentage of false alarms was again very low (1.3%) and was not further analyzed. All reported F-values are approximations to Wilks' lambda.

No-signal data

Like in Experiment 1, CRTs were analyzed by means of a 2 (trial n : Repetition vs. switch) by 4 (trial $n-1$: No-signal, invalid signal, signal-respond, signal-inhibit) repeated measures MANOVA. Results are presented in Table 5.5. There was a switch cost on trial n , $F(1,18) = 42.41$, $p < .001$, and an effect of trial $n-1$, $F(3,16) = 129.33$, $p < .001$. Both main effects interacted significantly, $F(3,16) = 13.33$, $p < .001$. There was a switch cost when the previous trial was a no-signal trial, $t(18) = -3.54$, $p < .005$. We also found a switch cost when an invalid stop signal was presented on trial $n-1$, $t(18) = -7.16$, $p < .001$, or when participants responded when a valid stop signal was

presented, $t(18) = -6.22, p < .001$. However, there was no switch cost after a signal-inhibit trial, $t(18) = 1.40, p = .18$.

For the error data, the 2 (trial n : Repetition vs. switch) by 4 (trial $n-1$: No-signal, invalid signal, signal-respond, signal-inhibit) repeated measures MANOVA, revealed a main effect of trial $n-1$, $F(3,16) = 61.33, p < .001$. There was no main effect of task switching, $F < 1$. The interaction tended to be marginally significant, $F(3,16) = 3.03, p = .06$. We found only a switch cost after a no-signal trial, $t(19) = -2.61, p < .05$. There was no switch cost after an invalid stop signal, $t(18) = .77, p = .25$, after a signal-respond trial, $t(18) = 1.40, p = .18$, or after a valid stop signal, $t(18) = .50, p = .62$.

Table 5.5: Choice reaction times (CRT) and error percentages (E%) in Experiment 2 (SDs in parentheses) of repetition trials and switch trials as a function of the signal properties of trial $n-1$. The switch cost was computed by subtraction the means of repetition trials of the means of the switch trials ($\dagger p < .05, * p < .005; ** p < .001$).

	Trial n-1							
	No-signal		Invalid signal		Signal-respond		Signal-inhibit	
	CRT	E%	CRT	E%	CRT	E%	CRT	E%
Repetition trial	616 (90)	4.1 (4.2)	656 (21)	4.7 (1.1)	719 (26)	4.1 (2.5)	702 (19)	3.0 (0.7)
Switch trial	668 (110)	5.8 (5.5)	714 (48)	4.5 (0.5)	763 (47)	3.5 (1.9)	699 (19)	2.8 (1.7)
Switch cost	52*	1.7†	58**	-0.2	44**	-0.6	-3	-0.2

Signal-data

Signal-data are presented in Table 5.6. Again, the staircase tracking procedure produced good results (probability of responding given a stop signal was .51). Response inhibition in the selective stop task at a perceptual level was also influenced by task switching, $t(19) = -2.73, p < .05$. When a valid stop signal occurred but participants responded, a switch cost was

observed, $t(19) = -3.93, p < .001$. This was also the case when an invalid stop signal was presented, $t(19) = -2.80, p < .05$.

Table 5.6: Stop signal reaction times (SSRT), signal-respond RTs (V-SRT) and RTs of invalid stop trials (IV-SRT) in Experiment 4 (SDs in parentheses; * $p < .05$; ** $p < .005$).

	SSRT	V-SRT	IV-SRT
Repetition trial	277 (108)	575 (71)	758 (119)
Switch trial	306 (116)	632 (90)	814 (107)
Switch cost	29*	57**	56*

DISCUSSION

The results of Experiment 2 are straightforward. First of all, we replicated the interaction of Experiment 1 between response inhibition and task switching, indicating that there are indeed common mechanisms or shared resources in both types of tasks. Secondly, we predicted no switch cost after a signal-inhibit trial because no response selection had to be made in the primary task. This hypothesis was confirmed. These results are in line with the findings of Verbruggen et al. (2005a) and suggest that the finding of Experiment 1 that a switch cost was present after a signal-inhibit trial was not simply due to the fact that a selective stop task was used. However, there remains another mediating factor that can have contributed to the present results.²³ After all, there are no response repetitions after a signal-inhibit trial and it is a common finding in the literature about task switching that the switch cost is smaller for a response alternation (see e.g., Rogers & Monsell, 1995; Meiran, 2000). Thus, if the effects of task switching in Experiment 2 are only due to response repetition trials, no switch cost is expected after a signal-inhibit trial, regardless of whether participants had to make a response selection or not. Therefore, in order to exclude this

²³ We would like to thank Ulrich Mayr for this suggestion.

possibility, we performed post-hoc analyses for both experiments and looked what the influence of response alternations was in our study.

EXPERIMENT 1 AND 2: RESPONSE REPETITIONS VS. RESPONSE ALTERNATIONS

For no-signal trials in both experiments, we analyzed the effect of response repetitions vs. response alternations on the switch cost by means of a 2 (response: Repetition vs. alternation) by 2 (task: Repetition vs. alternation) repeated measures ANOVA. In Experiment 1, there were main effects of response alternation, $F(1,19) = 45.01, p < .001$, and task alternation, $F(1,19) = 38.38, p < .001$. As can be seen in Table 5.7, both main effects interacted, $F(1,19) = 16.49, p < .001$. Post-hoc two-tailed t-tests revealed that the switch cost was significant for both response repetitions, $t(19) = -6.55, p < .001$, and response alternations, $t(19) = -2.48, p < .05$. Thus, although the switch cost was significantly smaller for a response alternation, the switch cost was still significant. Interestingly, the switch cost for a response alternation, was statistically not different from the switch cost found after a signal-inhibit trial (21 ms vs. 16 ms), $F(1,19) < 1$.

In Experiment 2, similar results were found. There was a marginally significant main effect of the response alternation, $F(1,18) = 3.63, p = .07$, and a significant effect of task alternation, $F(1,19) = 15.17, p < .001$. The interaction between both main effects was again significant, $F(1,19) = 8.54, p < .01$. Two-tailed t-tests revealed that the switch cost was significant for both response repetitions, $t(18) = -3.81, p < .01$, and response alternations, $t(18) = -3.54, p < .01$.

In sum, the fact that there are no response repetitions after a signal-inhibit trial cannot explain why there is no switch cost observed after this type of trial in Experiment 2. On the other hand, it can explain why the switch cost is smaller after a signal-inhibit trial compared to the trial that followed a no-signal trial in Experiment 1. When we looked only at trials that followed a no-signal trial but where the response alternated, there was no longer a difference in switch cost. This can also be seen as extra evidence

for the fact that response selection, or task application, and not response execution is the crucial factor in task switching.

Table 5.7: Choice reaction times (CRT) in both experiments (SDs in parentheses) of repetition trials and switch trials for both response repetitions and response alternations. The switch cost was computed by subtraction the means of repetition trials of the means of the switch trials ($\dagger p < .05$, $* p < .005$; $ p < 001$).**

	Experiment 1		Experiment 2	
	Response repetition	Response alternation	Response repetition	Response alternation
Task repetition	674 (106)	772 (148)	617 (101)	647 (88)
Task alternation	746 (135)	793 (154)	682 (112)	679 (101)
Switch cost	72**	21†	65*	32*

GENERAL DISCUSSION

In the present study, we further investigated the role of response selection in task switching. Schuch and Koch (2003) demonstrated that after a no-go trial without response selection, no switch cost was observed. They interpreted these findings as evidence for the hypothesis that response selection on the previous trial is necessary to observe a switch cost on the current trial. A similar data pattern was observed by Verbruggen et al. (2005a) who used a simple stop task. By using two different selective stop signal tasks in the present study, the hypotheses that the response selection is the mediating factor, was further investigated. We used selective stopping requiring a response selection in the primary task in Experiment 1 and selective stopping requiring a perceptual discrimination in the selective stop task in Experiment 2. In the first type of the task, participants had to select the (correct) response in the primary task before they knew the validity of the stop signal. In perceptual version of the stop task, the validity of the stop

signal was determined by the pitch of the tone, and this could be done independent of the primary task.

Results of both experiments are straightforward. In both experiments, we found a switch cost after a no-signal trial and after an invalid stop signal, which is of course not surprising. But the most important comparison between both experiments was what happened after a valid stop signal. Both experiments had in common that participants slowed down their responses when a stop signal was presented on the previous trial, irrespective of the validity of the stop signal. This post-signal adaptation is a common finding in the literature about the stop signal task (see Logan, 1994) and suggests that strategic factors come into play. However, besides this common post-signal adaptation, there was an important difference between both experiments regarding what happened after a signal-inhibit trial. In Experiment 1, there was a switch cost both after a signal-respond and after a signal-inhibit trial. In Experiment 2, this was not the case: Only after signal-respond trials, the switch cost was present. Therefore, this experiment also dissociates neatly between the effect of stop signal presentation (i.e., go vs. no-go trials in terms of the go/no-go paradigm) and the effect of stopping itself: Successful inhibition and not signal presentation cause the disappearance of the switch cost.

This difference between the two forms of selective stopping has some important implications. First of all, in both experiments, after a signal-inhibit trial a switch occurred from a signal trial to a no-signal trial. Thus the problem of additivity of Schuch and Koch (2003) is absent since we dissociated between the two forms of selective stopping. Secondly, the presence of a switch cost after a signal-inhibit trial in Experiment 1 is indeed in line with the hypothesis that response selection is a mediating factor in task switching. This was previously suggested by Schuch and Koch (2003) and Verbruggen et al. (2005a). Participants had to apply the task set and make a response selection before they knew whether they had to stop or not and we argue that this caused the switch cost after a signal-inhibit trial in Experiment 1.

Additionally, Experiment 1 demonstrated beyond doubt that response execution was not necessary to obtain a switch cost. At first sight, the switch

cost after a signal-inhibit trial was smaller than after a no-signal trial [37 ms vs. 16 ms; $F(1,19) = 4.77, p < .05$]. However, post-hoc analyses revealed that this difference is probably due to the difference between response repetitions and response alternations. The switch cost was significantly higher for a response repetition, which is a common finding in the literature about task switching (see e.g., Rogers & Monsell, 1995; Meiran, 2000) and after a signal-inhibit trial, there are no response repetitions, simply because no response was executed. Therefore, in Experiment 1 we compared the switch cost found after a signal-inhibit trial with the switch cost found for response alternations. Interestingly, there was no longer a difference in the switch cost. This finding can be interpreted as extra evidence that response selection is an important mediating factor in task switching and that response execution is clearly not necessary to observe a switch cost on the next trial.

We mentioned already in the introduction that there is also an alternative account for the findings of Schuch and Koch (2003). Kleinsorge and Gajewski (2004) suggested that in a go/no-go paradigm, participants are less willing to prepare the task in advance because they know that a no-go trial may occur. This motivational account, proposed for the go/no-go paradigm, can also easily explain the data of Experiment 1. Participants knew in this experiment that whether they had to stop or not, the stimuli had to be processed and a response selection had to be made. Thus, preparation in advance would be beneficial. This could indeed explain why we found a switch cost in Experiment 1. However, due to the differences in the go/no-go paradigm and the selective stop paradigm that was used in Experiment 2, it is more complicated and therefore, probably harder to explain the data pattern of this experiment in terms of the motivational account of Kleinsorge and Gajewski. In a go/no-go paradigm, the effect of motivation is dependent on the context (Kleinsorge & Gajewski, 2004). Alternatively, it was suggested by several authors that strategic adjustments in the stop signal task are based on the properties of the previous trial (e.g., Logan, 1994). For example, after signal-respond trials, participants tend to make strategic adjustments, and are more cautious to respond compared to no-signal trials. The CRT data of Experiment 1 and 2 demonstrated that

participants were indeed more cautious and that they tended to slow down their responses after signal-respond trials, compared to no-signal trials. These findings are in favour of some kind of trial-based strategic adjustment. But even though adjustments were made after signal-respond trials, there was still a switch cost in both experiments. Thus, this seems to suggest that these motivational/strategic differences induced to the failure of response inhibition in the stop task, cannot fully explain the present data pattern and previous results of Verbruggen et al. (2005a). On the other hand, given the above mentioned differences between the go/no-go paradigm and the stop signal paradigm, one has to be careful in generalizing the results of the present study. Also, as pointed out by T. Kleinsorge (personal communication), these differences between paradigms make it rather difficult to formulate, based on the Kleinsorge and Gajewski account, specific predictions about the motivational consequences of the selective stop task. All in all, the results of the present paper do not necessarily contradict the results of Kleinsorge and Gajewski (2004), but seem to suggest that there are at least differences in motivational effects of the go/no-go task and the stop signal task.

Another inevitable question is what actually becomes inhibited when a stop signal is presented. Mostly, it is assumed that stop signal inhibition is targeted on the inhibition of the response execution (see e.g., Band & Van Boxtel, 1999, for a neuroanatomical model). Although the present study does not allow any strong conclusions, one could also hypothesize that under certain conditions, not only the response execution becomes inhibited, but probably also the whole task set. In Experiment 1, the task sets have to be activated and applied. This allows a response selection and based on the result of this response selection, a response is selectively inhibited or executed. In other words, the task set may not be inhibited because the task set is needed to perform correctly the response inhibition. This is in line with Logan et al. (1986), who suggested also that in a simple stop task, all responses become inhibited whereas in the selective stop task used in Experiment 1, inhibition is focused on a single response. This picture could change in Experiment 2. Here, response selection and task set application in the primary task are no longer needed when a stop signal is presented.

Under these conditions, one could hypothesize that not only the response execution becomes inhibited, but also the whole task set. If the task set is also inhibited when a stop signal is presented, one expects no longer a difference after a signal-inhibit trial between task repetitions and task alternations. This is because for both types of trials, the task set was inhibited on the previous trial, and as a consequence, task repetition would no longer be beneficial. Note that this explanation does not contradict the hypothesis that response selection is necessary in task switching. After all, we argue that response selection is an important mediating factor, but not a causing factor.

The results of the present study can also be related to the proposal of Wylie and Allport (2000), who suggested that part of the switch cost is due to interference caused by the retrieval of stimulus-response associations. The possibility that stimulus-response associations are differentially influenced by simple and selective stopping is also supported by another paradigm. Verbruggen, Liefoghe and Vandierendonck (2005b) found that the negative priming effect (i.e., slower reactions when the target was previously ignored) disappeared after a signal-inhibit trial in the simple stop task, but not in a selective stop task similar to the one used in Experiment 1 of the present study. Recently, Rothermund, Wentura and De Houwer (2005) suggested that negative priming is also due to the retrieval of stimulus-response associations. Given the similarity of both designs, we therefore suggest that in both studies stimulus-response associations are established after a valid stop signal in the selective stop task at response level, even without the actual response execution.

Besides the fact that we demonstrated that response selection without response execution is sufficient for the establishment of a switch cost, there was still another important finding in both experiments. Both forms of selective stopping interacted with task switching. Verbruggen et al. (2005a) did not find such an interaction with simple stopping. However, it is not surprising to find such an interaction. First of all, Logan, Kantowitz, and Riegler, (1986) already demonstrated that the selective stop task was more susceptible for manipulations in task difficulty, probably due to the higher cognitive demands - indicated by larger SSRTs in selective stopping

compared with simple stopping. These authors demonstrated that inhibiting one out of four responses was more difficult than inhibiting one out of two responses in the selective stop task. Secondly, neuroimaging data demonstrated that there is at least a neuroanatomical overlap between response inhibition and task switching. More precisely, Aron, Robbins, and Poldrack (2004) suggested on the basis of a meta-analytical study that the right-inferior cortex is strongly activated in both the stop signal task and the task switching paradigm, suggesting the right inferior cortex might play an important role in inhibition processes in different types of tasks.

Based on the findings of the present study and the study of Aron et al. (2004), we can hypothesize that the same inhibitory processes work in the selective stop task and in the cued task switching paradigm. However, it might also be the case that it is not necessarily the inhibition in task switching that interacts with the response inhibition in the selective stop signal task. First of all, several authors suggested that the inhibition of task switching is a more lateral kind of inhibition (e.g., Schuch & Koch, 2003). Mayr and Keele (2000, p. 22) also suggested that the inhibitory process involved in task-switching may be 'relatively impenetrable for higher-level control' and preferred the notion of lateral inhibition above the concept of a more active form of self inhibition. Secondly, in a recent paper, Derrfuss, Brass and von Cramon (2004) found evidence for cognitive control in the posterior frontal cortex. This region was commonly activated in task switching, an interference task (these authors used the Stroop task), and an n-back working memory task. Based on these results, they suggested that the common activation is due to the amount of cognitive control in those different tasks. Given the fact that selective stopping requires a more cognitive controlled stop, it seems plausible to assume that the interaction between task switching and response inhibition in the selective stop task is not necessarily due to common inhibitory mechanisms. Instead, the interaction may be due to the higher cognitively control in both paradigms.

In sum, the present study demonstrated that response selection, even without response execution, is indeed an important factor in task switching. In other words, only when the task set is applied, a switch cost is observed on the next trial. This finding is in accordance with the accounts of Schuch

and Koch (2003) and Wylie and Allport (2000). Moreover, although it is still unclear where the overlap is precisely situated, the present data pattern also suggests that task switching and response inhibition in the selective stop task seem to rely on common structures or mechanisms.

CHAPTER 6

GENERAL CONCLUSIONS

In this final chapter, I will briefly summarize the results of the empirical studies and attempt to integrate these findings in the present theories and models. The overview and discussion will fall apart in four different subsections: (a) results of Chapters 2 & 3 and the implications for selective suppression in conflict tasks; (b) results of Chapters 4 & 5 and the role of response selection in the establishment of stimulus-response associations and the interference effect; (c) some comments on the underlying processes in the stop signal paradigm; and finally, (d) some general remarks on the concept of 'inhibition'. Hence, the first subsection is exclusively related to Chapters 2 & 3 whereas the second subsection deals with the findings of Chapters 4 & 5. After those two sections, we will focus on the implications for the stop signal paradigm and the relation between different kinds of inhibition based on the results of all four chapters. In a final part, some directions for future research on inhibition are provided.

RESEARCH OVERVIEW AND IMPLICATIONS

This doctoral thesis fits in with the vast amount of studies that investigate the concept of inhibition and interference. For the main part, we focused on the relation between different kinds of inhibition. Previous research suggested important differences between different forms or kinds of inhibition while others pointed out that there might also be some overlap or commonalities (Dempster, 1993; Harnishfeger, 1995; Nigg, 2000). In the four empirical chapters, we focused on (a) the relation between stop signal inhibition and other kinds of inhibition or interference control, and (b) on the influence of stop signal inhibition on the establishment of interference. In this context, 'interference' refers to what causes the need for within-trial adjustments and we use 'interference control' to label these adjustments.

Our research was largely based on the proposition that these within-trial adjustments are performed by an active suppression of the features that caused the interference in the first place (e.g., Burle, Possamaï, Vidal, Bonnet

& Hasbroucq, 2002; Eriksen & Schultz, 1979; Ridderinkhof, 2002a). And what is more, in regard to this distinction between interference and interference control, the four empirical chapters can be grouped into two parts. In the first two chapters, we investigated selective suppression and its relation with response inhibition in the stop signal task, whereas in the other two chapters, we focused on the effect of response inhibition on interference on the next trial as well.

SELECTIVE SUPPRESSION AND THE RELATION WITH RESPONSE INHIBITION

A great advantage of the stop signal paradigm (Lappin & Eriksen, 1966; Logan & Cowan, 1984; Logan, 1994) is that the primary task can nearly be any reaction time task. One of the primary tasks that has been used, is the flanker task. The difference between the flanker task and a standard choice reaction time task is that in the flanker task the target is flanked by distracting information. One of the emerging findings was that stop signal reaction times were prolonged in flanker incongruent trials (Kramer, Humphrey, Larish, Logan & Strayer, 1994). Later on, this was replicated by Ridderinkhof, Band and Logan (1999). These latter authors suggested that this effect of flanker congruency on response inhibition was due to the need for selective suppression in the flanker task in case of an incongruent trial. Because of the fact that selective suppression of the irrelevant response and stop signal inhibition rely on common mechanisms and compete with each other, the SSRTs were longer on incongruent trials.

In Chapter 2, we started from this 'common mechanism' hypothesis of Ridderinkhof et al. (1999) and our purpose was twofold: (a) replicating the findings of Kramer et al. (1994) and Ridderinkhof et al. (1999) with other interference or conflict tasks; and (b) investigating the nature of selective suppression in these different conflict tasks and the relation with stop signal inhibition. In the first study of this chapter, we used a flanker task and Stroop task in which we introduced distractors that were not part of the response set but that were categorically related to the responses

(Verbruggen, Liefoghe, & Vandierendonck, 2004). In this study, the conflict is assumed to be situated at an intermediate processing stage, concerning the semantic attributes of a stimulus. In the second study of this chapter (Verbruggen, Liefoghe, & Vandierendonck, in press), we focused on a perceptual conflict which was situated at an early processing level. For this purpose, we used a global/local task and a modified version of the flanker task with stimulus incongruent flankers. In real terms, the difference between the first and the second study of Chapter 2 is that in the first study, the distractors that were not part of the response set could never become the target (e.g., participants never had to respond to an upward pointing arrow, although this arrow could flank leftward or rightward pointing arrows). In the second study, the distractors were part of the response set. For instance, stimulus incongruent distractors used in the flanker task of the second study were mapped onto the same response as the target, but were physically different. Although this distinction between processing levels may be subject to discussion, the main point is that unlike the study of Ridderinkhof et al. (1999), these different types of conflict are not situated at a response-related processing stage.

By analogy with this latter study, we combined the stop signal task with various conflict tasks and looked at the effect of the distinct types of conflict on response inhibition. The main observation was that in a variety of conflict tasks, similar effects of congruency were observed. The different types of stimulus-stimulus congruency –the term that we will use to describe the interference effects of interest in Chapter 2– all interacted with response inhibition in the stop signal task. In all four experiments, this was indicated by longer SSRTs for stimulus incongruent trials compared to SSRTs of congruent or neutral trials. Moreover, in Chapter 3, we ran an experiment with a spatial Stroop/Simon task that is assumed to operationalize stimulus and response conflict independently (Liu, Banich, Jacobson & Tanabe, 2004). Results of that experiment demonstrated that the effects of both types of conflict were highly comparable.

These findings obtained with the combined congruency/stop signal task, have two important implications. First, we replicated in different

paradigms the results of Kramer et al. (1994) and Ridderinkhof et al. (1999) and observed once more an interaction between interference control in various conflict tasks and response inhibition in the stop signal task. We argue that this provides additional evidence for common underlying mechanisms, as initially proposed by Logan (1994) and Ridderinkhof et al. (1999). This common mechanism is responsible for both the suppression of irrelevant stimulus features that cause the interference, and the inhibition of motor responses in the stop signal task. A second important finding of the stop signal experiments of Chapters 2 & 3 was that conflict or interference did not have to be situated at a response-related processing stage in order to involve suppression mechanisms. Based on the logic of Ridderinkhof et al. (1999) and Logan (1994), the observed interaction of stimulus interference and stop signal inhibition indicates that both forms of inhibition have something in common. As a consequence, these experiments in which an interaction was found tell us something about the nature of selective suppression itself. We argue that our results demonstrate that there is suppression of irrelevant stimulus features, independent of the processing level, and that this form of selective suppression interferes with inhibition at a motor level.

To substantiate the claim about interference control at different processing stages, we performed a study without the stop signal task and focused entirely on the nature of stimulus interference. We hypothesized that if the same within-trial adjustments are made for stimulus- and response-related interference, it should be possible to observe similar between trial-adjustments. Gratton, Coles, and Donchin (1992) observed in a flanker task that after an incongruent trial, the flanker effect became smaller on the next trial. This finding has been replicated frequently (e.g., Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; see also Botvinick et al., 2001). It was argued that the smaller congruency effect on a trial following an incongruent trial was due to top-down adjustments to resolve a conflict

situation.²⁴ Not everybody agreed with the notion of top-down adjustments after conflict trials and explained the Gratton effect by means of stimulus-response repetition effects (e.g., Hommel, Proctor & Vu, 2004; Mayr, Awh, & Laurey, 2003; Notebaert, Soetens, & Melis, 2001). Nevertheless, it seems that when one controls for those repetition effects, there is still evidence for a top-down explanation (Kerns et al., 2004; Notebaert, Gevers, Verbruggen & Liefoghe, in press; Wuhr, in press). Therefore, we used the conflict adaptation pattern as a marker for behavioural adjustments after incongruent trials and looked at the influence of the type of congruency. If stimulus conflict and response conflict are similar in nature, we expected that the stimulus conflict would be absent or at least become smaller after stimulus incongruent trials, similar to the conflict-adaptation pattern after response incongruent trials. And in fact, that was what we observed in the third study of Chapter 2: The stimulus congruency effect was absent after stimulus and response incongruent trials (Verbruggen, Notebaert, Liefoghe, & Vandierendonck, in press). Contrary to our expectations, the mere response congruency effect did not change. Future research is probably needed here to resolve this issue.

THE ACTIVATION-SUPPRESSION HYPOTHESIS EXTENDED

We started from the hypothesis that selective inhibition is needed to control for the interference. This hypothesis was formalized by Ridderinkhof: The activation-suppression hypothesis (2002a). Since the activation-suppression hypothesis clearly situates conflict at a response-related stage, the results of the first two chapters have some implications for the activation-suppression hypothesis. In this section, we will propose an extended version of the activation-suppression hypothesis by incorporating stimulus conflict.

²⁴ Since the effect of these adjustments is only observable on the subsequent trial, we talk about between-trial adjustments.

Ridderinkhof (2002a) started from a dual-route model (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Ridderinkhof, 1997; Ridderinkhof, van der Molen, & Bashore, 1995), assuming that irrelevant distracting information (e.g., the flankers) is processed automatically along a direct route. As a consequence, a response is activated. Meanwhile, the relevant information (e.g., the target in a flanker task) is processed via an attentive processing route with a target selection and a stimulus-response translation, and the response associated with the target becomes activated. This implies that on incongruent trials, there will be two responses active at a certain point in the processing stream. These two activated responses will interfere with each other and to resolve this conflict, it is hypothesized that the response associated with the irrelevant stimulus information will be suppressed by a super-imposed inhibitory mechanism (Ridderinkhof, 2002a).

However, the selective suppression of incorrect responses cannot explain our results obtained with conflict tasks in which the conflict was not necessarily situated at a response-related stage. As an answer, we suggest that selective suppression of irrelevant features can occur at any level in the processing stream, from stimulus perception to response execution. Conflict is here defined as 'at a certain processing stage common activation of two or more stimulus features that compete for activation and only one of them is associated with the relevant stimulus attribute'. As a consequence, there is not only a need for selective suppression of incorrect and irrelevant responses, but there is also need for selective suppression of any stimulus feature that becomes concurrently activated at any point in the processing stream. The extended activation-suppression hypothesis is depicted in Figure 6.1.

A key feature in our model is the incorporation of different processing stages. This distinction between different processing stages is not new. Sternberg (1969) proposed that there are four different stages of processing: Stimulus encoding, serial comparison, binary decision and response organization. More or less in accordance with the proposal of Sternberg, our model assumes a processing stream with different stages: (a) a perceptual

stage with regard to specific items and at which the relevant attribute or stimulus feature is selected; (b) a more intermediate or central stage, for example concerning the relevant abstract attribute; and (c) a response stage where the correct response should be selected and subsequently, executed (adapted from Liu, Banich, Jacobson, & Tanabe, 2004, p. 1097). Note that we do not make any statements concerning the serial or parallel nature of these processing stages. For example, Sternberg (1969) suggested that processing should be completed before one could move on to the next stage, whereas Eriksen and Schultz (1979) suggested that during processing there is a continuous accumulation of information. However, whether our model is discrete or continuous, is in our opinion of minor importance at this point.

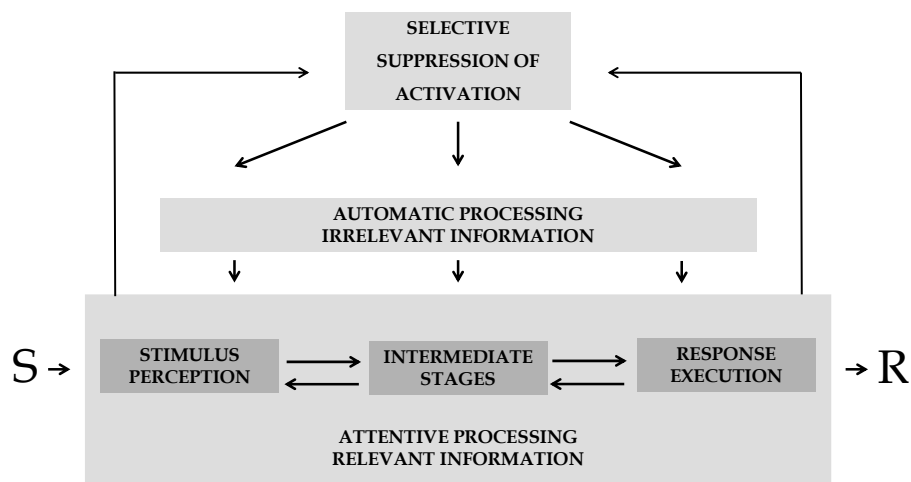


Figure 6.1: The activation-suppression hypothesis extended

By incorporation of a stage-like theory about information processing in the activation-suppression hypothesis of Ridderinkhof (2002a) we get a model that can account for the results of Chapter 2. Conflict can occur at the different processing stages, this conflict needs to be resolved and this is done by an inhibitory mechanism. As a result, response inhibition in the stop signal task will be more difficult in stimulus incongruent trials because of

the interaction between selective suppression and stop signal inhibition. Moreover, assuming that conflict can be situated at different processing levels can also explain why we were able to demonstrate that conflict at not-response-related processing levels has consequences for the performance on the next trial. Apparently, behavioural adjustments are made when a stimulus conflict was detected on the previous trial. Thus, both within-trial and between-trial adjustments are made after a conflict situation, regardless of the processing stage at which the conflict occurred.

To conclude, we suggest that the results obtained in Chapters 2 & 3 provide some nice evidence for this suggestion of control mechanisms at different stages in the processing stream. This resulted in the extended activation-suppression hypothesis, although the proposed ideas are not entirely new. For example Logan and Cowan (1984) hypothesized in their '*executive act of control*' model that cognitive control could operate at any point from stimulus perception to response execution. Our proposal is also in line with several neuroimaging studies. Several studies demonstrated that brain regions, such as the dorsolateral prefrontal cortex that are assumed to be in control in case of response conflict, are also active for other types of conflict (Liu, Banich, Jacobson, & Tanabe, 2004; Milham, et al., 2001; Van Veen, Cohen, Botvinick, Stenger & Carter, 2001). In other words, there is converging evidence that the same, or at least highly similar, top-down mechanisms can operate in different types of conflict tasks.

AFTER-EFFECTS OF RESPONSE INHIBITION

In the first two empirical chapters of this doctoral thesis, we focused entirely on selective suppression in conflict tasks and the relation with response inhibition. In line with Chapters 2 and 3, we investigated in Chapters 4 and 5 the influence of different kinds of inhibition on the stop signal task. Based on the taxonomy of Nigg (2000), one could argue that in Chapters 2 and 3 we have found interactions between different kinds of effortful inhibition. In Chapters 4 and 5, we wanted to investigate whether the same results are found with less effortful kinds of inhibition, like

negative priming (Nigg, 2000). In addition, we also focused in Chapters 4 & 5 on the effects of response inhibition on the subsequent trial.

In Chapter 4, we combined the negative priming paradigm (for reviews, see May, Kane, & Hasher, 1995; Fox, 1995) with the stop signal paradigm and this for two distinctive reasons. First of all, it was hypothesized by Rieger and Gauggel (1999) that after-effects in the stop signal task (referring to the observation that participants were slower when on the previous trial a stop signal was presented) were related to negative priming. Secondly, in the first two chapters we focused on the interaction between selective suppression and response inhibition. Whereas in the taxonomy of Nigg (2000) these two kinds of inhibition are considered as effortful, negative priming is considered as an automatic form of cognitive inhibition. Therefore, the negative priming paradigm seemed suitable to investigate similarities between after-effects and whether or not stop signal inhibition was influenced by less effortful forms of inhibition.

In regard to the first research question, the results of our negative priming study were very straightforward. Nor for simple stopping, nor for selective stopping any effect of negative priming on stop signal inhibition was found: The SSRTs on ignored repetition trials and control trials did not differ from each other. This seems to suggest that whatever causes the negative priming effect on the probe trial, it is not related to response inhibition. According to the inhibition account (e.g., Tipper & Cranston, 1985), negative priming results from persisting inhibition from the previous trial. Especially when this persisting inhibition is response-related, as previously suggested by some researchers (e.g., Houghton & Tipper, 1994), one would expect an effect of negative priming on stop signal inhibition. On the other hand, several researchers argued that negative priming is due to interference because of the retrieval of information related to the prime trial (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992; Rothermund, Wentura, De Houwer, 2005). If the latter is indeed the case, then this interference is resolved by a mechanism that is not related to stop signal inhibition, since stopping performance is preserved on ignored repetition trials.

Of course, we believe that the suppression mechanism does contribute to the establishment of the negative priming effect on trial $n-1$, since the distractor that becomes the target was actively inhibited on the previous trial. However, this has no consequences for response inhibition on the subsequent trial. For response inhibition, on the contrary, the opposite pattern was found: The negative priming effect disappeared completely when participants inhibited their response on the previous trial in the simple stop task. In this version of the stop task, all responses should be inhibited when a stop signal is presented. But when the participants had to select and process the target in order to know whether they had to stop or not, a negative priming effect was observed on the subsequent trial. This distinction between simple and selective stopping has at least two important consequences for the research on negative priming. First of all, our results demonstrate that response execution is not necessary to observe a negative priming effect on the subsequent trial. Secondly, our results indicate that participants have to discriminate between target and distractor in order to find a negative priming effect. Another way to put this is that the distinction between target and distractor should be relevant. We should make this qualification because it is difficult to know whether participants did or did not discriminate between target and distractor in the simple stop task. There are in fact only two things that we know for sure: (1) in the selective stop task, participants were obliged to discriminate between target and distractor when a stop signal was presented; and (2) when the stop signal is presented in the simple stop task the distinction between target and distractor is no longer relevant. Since it is difficult (or even impossible) to know whether or not participants discriminated between the target and distractor on signal-inhibit trials, it could be the case that not the target/distractor distinction is of importance, but rather the relevance for the correct performance in the current task.

In a next step, we investigated whether the effect of response inhibition on the subsequent trial in a negative priming design could be generalized to another paradigm, namely the task switching paradigm (Chapter 5). The negative priming paradigm and the task switching paradigm have in

common that performance on the current trial is influenced by the properties of the previous trial. Besides, Schuch and Koch (2003) reported a study in which they introduced go/no-go trials in cued task switching. These authors found that there was no switch cost when the previous trial was a no-go trial. Thus, based on the findings of Chapter 4 and based on the Schuch and Koch paper (2003), we expected that the switch cost would also be absent after signal-inhibit trials. Moreover, unlike Schuch and Koch (2003), we could also look at the effect of task switching on response inhibition.

We replicated the results of the negative priming study and the results of Schuch and Koch (2003). There was no switch cost after a successfully inhibited response in the simple stop task. On the other hand, when participants had to make a response selection to know the validity of the stop signal in a selective stop task, and as a consequence, before the response could be inhibited, a switch cost was observed on the next trial. We concluded therefore in Chapter 5 that response selection is a mediating factor in the establishment of the switch cost whereas response execution was apparently of minor importance. However, Wylie, Javitt and Foxe (2004) performed a similar experiment and they obtained different results. Wylie et al. introduced no-go trials in a task switching paradigm and subjects only responded on the letter trials if the stimulus contained a vowel and on the number trials if the stimulus contained an even number. In all cases, they responded with their right index finger. In other words, participants also had to process the stimulus to know whether the trial was a go trial or a no-go trial. But even though they had to process the stimulus of the primary task, there was no switch cost observed after a no-go trial. This seems to contradict our results. A possible explanation for these different findings is that in our study, there were always two different responses (a left-handed response and a right-handed response), whereas there was only one possible response in the study of Wylie et al. (2004). Given the importance of the response selection, it seems plausible that this difference in response selection demands could have contributed to the discrepancy between our study and the study of Wylie et al. (2004).

Anyway, our results are in accordance with the hypothesis of Koch and colleagues (Koch & Phillip, in press; Schuch & Koch, 2003) that response selection is a mediating factor in the establishment of the switch cost. In the Schuch and Koch paper, it was proposed that at the level of response selection, the relevant task-specific category-response rule is applied and the irrelevant rule becomes inhibited. As a result, application of the previously inhibited category-response rule will result in a task-switching cost: The residual switch cost. In a follow-up study of Koch and Phillip (in press) in which the same methodology of the Schuch and Koch study was used, Koch and Phillip pointed out that there might also be a task-repetition benefit: Activation of the category-response rule will result in a benefit on the next trial when the same rule can be applied. Obviously, this benefit could only occur after a go-trial, and it appeared that this benefit largely predicted the results obtained in their follow-up study. Note that, as pointed out by Koch and Phillip (in press), both accounts do not exclude each other.

Besides the effect of stop signal inhibition on the next trial in the task switching experiments, we were also interested in the effects of task switching on response inhibition. Contrary to what could be expected on the basis of the hypothesis that there is an overlap between response inhibition and task switching (Aron et al., 2004), we did not find any effect of task switching on response inhibition. SSRTs of task-repetition trials were not different from SSRTs of task-alternation trials. On the other hand, selective stopping was more difficult in task-alternation trials. We will come back later to this discrepancy between simple and selective stopping. But apart from this effect of task switching on selective stopping, we think that it is safe to conclude that after-effects of inhibition like the negative priming effect and possibly also the task switch cost do not interfere with response inhibition in the stop task, at least not in the simple stop task.

**RESPONSE INHIBITION, RESPONSE SELECTION,
AND CARRY-OVER EFFECTS**

Results of the negative priming study and the task switching studies demonstrated that successful response inhibition influenced carry-over effects or after-effects of inhibition, even though there was a difference in what was inhibited on the previous trial. In the negative priming task a stimulus is inhibited, whereas category-response rules are probably suppressed in a task switching paradigm. Despite this difference, stop signal inhibition on the previous trial resulted in a disappearance of the negative priming effect and the switch cost.

In the previous section, we explained the results of the task switching studies in the light of the response selection account of Koch and colleagues. But our results are also in accordance with theories that assume that the switch cost is at least partly due to persisting interference and carry-over effects (e.g., Wylie & Allport, 2000; Hsieh & Liu, 2005).²⁵ A common explanation for the negative priming effect and the switch cost is the concept of 'stimulus-response associations'. This concept is used in a variety of paradigms, and is based on the assumption that when participants respond to a target, the stimulus and response are automatically linked. On the next trial, this information is automatically retrieved, causing interference. Wylie and Allport (2000) argued that the switch cost was partly due to such persisting interference. Because of the retrieval of previously learned associations between stimulus and response representations (i.e., stimulus-response bindings), participants are slower to respond when they have to switch between two different tasks (Wylie & Allport, 2000). Similarly,

²⁵ The switch cost is probably influenced by voluntary preparation (i.e., 'endogenous' control) and involuntary carry-over effects of inhibition and stimulus-response bindings from the previous trial (i.e., 'exogenous' influences) (Goschke, 2000; Monsell, 2003). In light of this distinction, we argue that stop signal inhibition has primarily consequences for the exogenous influences.

Rothermund, Wentura and De Houwer (2005) suggested that the negative priming effect was due to the automatic retrieval of stimulus-response associations. In the prime trial, the distractor becomes associated with the response given to the target. When the distractor of the prime trial becomes the target of the probe trial, the previously learned association is retrieved, causing interference. Note that this 'stimulus-response association' hypothesis of Rothermund et al. (2005) is not that different from the episodic retrieval account of Neill (Neill et al., 1992). But where Neill suggested that the 'do not respond' information becomes associated with the distractor, Rothermund et al. (2005) hypothesized that the response to the target will be associated with the distractor.

All in all, several researchers suggested that both in the domain of negative priming and task switching, automatic retrieval of information related to the previous trial will interfere with the processing in the current trial and therefore result in slower responses. Now in regard to the 'stimulus-response associations' or 'episodes', dependent on the theory, our results suggest that these associations or episodes can already exist when a response selection has taken place without response execution. The task switching studies provided direct evidence for this hypothesis: When participants had to make a response selection to know the signal validity, a switch cost was found after a signal-inhibit trial. In addition, the results of the negative priming experiment can be explained in a similar way: Participants had to suppress the upper two responses or the lower two responses. So, it seems reasonable to assume that they also made a response selection to know the validity of the stop signal. However, this could also be done by identifying the identity of the target, without actually selecting the response. Unfortunately, the selective stop task used in the negative priming study was in the first place not designed to investigate the role of response selection in negative priming, so it does not allow a discrimination between the two possibilities. But given the results of the task switching study and given the similarities of the results, we argue that response selection could indeed play an important role in the establishment of stimulus-response associations. In other words, a stimulus can become associated with a

response at the moment this response is selected and without the need for response execution.

Until now, we focused primarily on the cost of response selection on the previous trial. But we already mentioned that a part of the effect of stop signal inhibition could also be due to the fact that there is no response selection benefit as suggested by Koch and Philipp (in press). However, the data of the negative priming study and the task switching studies suggest that the disappearance after a signal-inhibit trial of the negative priming effect and the switch cost was largely due to faster ignored repetition trials and switch trials respectively. Furthermore, this also goes against the interpretation that our results could be due to the fact that there are no task repetition trials after a signal-inhibit trial. One could argue that participants got the impression that they were performing a different task on the previous trial. But if this would be the case, then one would expect that task-repetition trials that followed a signal trial were slower than repetition trials that followed a no-signal trial. Results of the study with simple stopping and cued task switching indicated that this was not the case. Therefore, we suggest that the absence of response selection will lead to a disappearance of the cost observed in paradigms like the negative priming paradigm and the task switching paradigm.

THE STOP SIGNAL PARADIGM AND ITS VARIANTS: RESPONSE INHIBITION AND BEYOND

The stop signal paradigm was the 'leitmotiv' of this doctoral thesis. Initially, we used the paradigm primarily for investigating the relation between response inhibition and other kinds of inhibition, such as interference control. By conducting the experiments, it turned out that the paradigm also offers a very useful method for investigating underlying processes in the primary tasks. We already discussed the findings in regard to what the stop signal experiments learned us about some primary task properties. But what are the consequences for the stop signal paradigm

itself? In this section, we will focus more on the stop signal task itself and the underlying processes in different variants of the stop task.

To start with, there are two 'minor' remarks. First of all, in the experiments of Chapter 2 and Chapter 3, blocks without stop signals were included to control for the effect of occasional presentation of stop signals on conflict in the primary task. This inclusion of control blocks led to two main findings. It appeared that knowing that stop signals could occur in a number of trials resulted in a more cautious response strategy of the participants. In the blocks with stop signals, reaction times were slowed down in all experiments and in two experiments (Experiment 1 of the first and second study of Chapter 2), participants also made fewer errors. However, in none of the experiments of Chapter 2 the congruency effect (i.e., the difference between congruent and incongruent trials) was influenced by the inclusion of stop signals. This can be of importance for the independence assumptions of the stop signal paradigm. In the past, the difference between observed and predicted signal-respond RTs was used to test the independence assumption. The simulations by Band et al. (2003) showed that this is probably not the best way of testing the assumptions. As a consequence, there are presently no direct techniques or methods for testing the assumptions. Therefore, we suggest that it might be fruitful to add a control block without stop signals, whenever the experimental design allows it. Another consequence is that we are able to generalize our results to congruency tasks without stop signal presentation, since it appeared that dealing with the conflict was the same for both types of blocks. The question remains why in Chapter 3 we did find a smaller compatibility effect in the blocks with stop signals. Probably, this has something to do with the time-course in the Simon task. In this task, it is a common finding that with increasing RT, the Simon effect decreases (e.g., Hommel, 1993, 1997), in contrast to the observation that longer reaction times in congruency tasks like the flanker task, Stroop task and global/local task do not result in smaller congruency effects (e.g., Hommel, 1997).

A second 'minor' remark concerns the finding that there was a large variability in the SSRTs through the different studies. Logan (1994) reported

that the average SSRT for adults was around 200 ms. When we compare the SSRTs in our experiments, stopping latencies of non-conflict trials in different experiments ranged from 144ms (in the flanker task with a 4-to-2 mapping) to 223ms (in the manual Stroop task). Of course, this is a between-experiments comparison, and one needs to be careful with such a comparison. On the other hand, it can be quite interesting, although we cannot offer an airtight explanation at the moment. As we see it, there can be several possibilities for this variability, such as individual differences, primary task properties, the way stop signals are presented (e.g., through headphones or not). Unfortunately, the experiments were not designed for this purpose, so we can only guess. We think that in the future it could be interesting to further investigate which –at the moment still unknown– factors contribute to stop signal performance in healthy subjects. In the end, this can tell us something more about the underlying processes in the stop signal paradigm, helping us to understand differences between groups and conditions.

This brings us to the main point of this section: What can the experiments we performed tell us about the underlying processes in the stop signal paradigm and its variants. For this we take as a starting point the suggestion of Aron and Poldrack (2005). They suggested that there are four different components or functions in the stop signal task: (1) *maintaining and successfully executing the task rules*; (2) *maintaining alertness/vigilance for the unpredictable occurrence of the stop signal*; (3) *processing the stop signal, which requires detecting it as the target for a different action/non-action and which may require shifting attention from the visual to the auditory domain*; and (4) *the response inhibition itself* (Aron & Poldrack, 2005, p.1289). In addition, in the selective stop task, there is need for an extra process to know the validity of the stop signal. This process that helps to determine the stop signal validity can be considered as a part of the third component suggested by Aron and Poldrack (2005).

In regard to this distinction between different components or functions, the comparison of different selective stop tasks and the simple stop task is most revealing since the SSRT differences in the task switching studies can

tell us something more about the underlying processes. Hsieh and Liu (2005) recorded the EEGs during task switching. Based on the inspection of among other things the LRP-component, they argued that task switching mainly influences the duration of the response selection stage which would be due to a carry-over effect. Furthermore, this effect can not be overcome by advance reconfiguration, such as task cueing (Hsieh & Liu, 2005). This is in line with what for example Allport and colleagues suggested (cfr. supra). All in all, it seems that the response selection process is more difficult on switch trials than on repetition trials. Now it could be the case that this difference in difficulty of response selection can explain why there are differences between response inhibition in the simple stop task and in the selective stop tasks, and that in the end can tell us something more about the underlying processes.

In the motor variant of the selective stop task a response selection has to be made before the response inhibition process can 'start' when a stop signal is presented. Now it seems reasonable to assume that this will also influence the estimation of the stopping latency. For the estimation of the SSRTs, we need to know two things: (1) when does the stop process start and (2) when does the stop process finish. In Chapter 1, we explained that both points in time are known. The starting point of the stop process corresponds to the moment a stop signal is presented. According to the horse race model, the race between the stop process and the go process starts (Logan & Cowan, 1984). But in the selective stop task, it is more complicated since there is an extra process: Participants have to decide whether they have to stop or not. The duration of this process is probably also incorporated in the SSRT. As a result SSRTs of switch trials will be longer compared to SSRTs of repetition trials, since the response selection that determines the validity of the stop signals, is prolonged on switch trials. Thus, it might be the case that differences between the SSRTs in the motor variant of the selective stop task are not only reflecting differences in duration of the response inhibition process itself but also differences in the process that is needed to determine the validity of the stop signal.

Similarly, it could be the case that the longer SSRTs for switch trials in the perceptual variant of the selective stop task are not entirely due to response inhibition. In the perceptual selective stop task, participants had to discriminate between a high and low tone: They had to identify the stimulus and decide whether they had to stop or not. In other words, there is an additional process and compared to the motor variant of the selective stop task, this process is independent of the processing in the primary task. In a sense, this results in some kind of dual-tasking since participants have to categorize the stop signal and meanwhile process the stimulus of the primary task. Note that in the motor variant of the selective stop task the stimulus that determines the validity of the stop signal is processed anyway. Now one could hypothesize that dual-task interference or PRP-like interference arises when a stop signal is presented.²⁶ The reason for this interference would be that response selection in the primary task interferes with the stop signal categorization (which determines the validity of the stop signal) of the selective stop task. Response selection takes longer on switch trials, and as a consequence, when a stop signal is presented the categorization process will be prolonged on these trials. We argued above that the duration of the process that determines the validity of the stop signal is probably also incorporated in the SSRT estimation. Thus, it could be the case that SSRT differences in the perceptual variant of the selective stop task are not really reflecting differences in response inhibition, but merely differences in stop signal processing.

Aron and Poldrack (2005) already suggested that the processing of the stop signal, which requires detection and may require an attentional shift, occurs probably also in the simple stop task. Now one could wonder whether the 'stop signal processing hypothesis' also holds for the simple stop task, explaining the SSRT differences found in various experiments. We have several reasons to believe why this is not the case. For a start, we did

²⁶ The psychological refractory period refers to a kind of dual-task interference when participants have to respond to two signals presented in rapid succession (see Pashler, 1994, for an overview).

not find any effect of task switching on simple stopping. Although this reasoning might be a bit circular, it seems that if task switching can result in dual-task interference or PRP-like interference, this does not influence stop signal processing in the simple stop task. Secondly, we think that the stop signal processing demands are higher in the selective stop tasks than in the simple stop task (at least for normal, healthy subjects). In the simple stop task, a stop signal is relatively easily detected and the stop process can start racing against the go-process, without any further discrimination or selection process that is needed in the selective stop tasks. Without this extra discrimination process, there is no reason to expect dual-task interference. We already mentioned in Chapter 1 that it was demonstrated that stop signal inhibition –at least the inhibition of not-yet executed actions– does not suffer from PRP-like effects. Logan and Burkell (1986) argued that there is very little interference when the second signal causing the PRP-effect is a stop signal. Later on, this was replicated by Horstmann (2003), who also found that in contrast to action termination the inhibition of a not-yet executed action did not suffer from PRP interference. Unlike selective stopping, we think that the results of those two PRP-studies provide evidence for our argument that the differences in SSRTs in the simple stop task can probably not be explained by assuming that the processing of the stop signal is more difficult in for example incongruent trials.

In sum, when we go back to the four different ‘components’ of the stop signal task proposed by Aron et al. (2005), we can look at which level the observed interactions between different kinds of inhibition occur. For a start, all our studies used a within-block manipulation, so this excludes the possibility that maintaining the task rules and maintaining alertness or vigilance can explain why stopping is prolonged in some kinds of trials.²⁷

²⁷ Note that maintaining the task rules and maintaining the alertness also did not influence the congruency effects much (cfr. the first remark of this section). One can expect that the demands are higher when stop signals could occur during the experiment, and therefore, that maintaining would influence the congruency effect. Apparently, this was not the case.

After all, it seems safe to expect that these functions or processes are the same for all types of trials. The third component proposed by Aron et al. (2005) refers to the processing of the stop signal. We argued above that this stop signal processing could be influenced in case of selective stopping, but it seems less likely that this could explain the results of the experiments with simple stopping. Thus, based on deletion of other possibilities, we suggest that the longer SSRTs in conflict trials are largely due to the response inhibition process itself. This is in line with the hypothesis that response inhibition in the stop signal task will interfere with other effortful kinds of inhibition because those types of inhibition rely on common underlying mechanisms. The implication of this hypothesis will be discussed below.

THE RELATION BETWEEN DIFFERENT INHIBITORY FUNCTIONS

So far we discussed the implications of our results for selective suppression mechanisms, inhibitory after-effects and carry-over effects, and made a few remarks about the nature of underlying processes in different variants of the stop signal task. But the most important topic of this doctoral thesis is without doubt the relation between different kinds of inhibitory functions. 'Inhibition' is no longer considered as a unitary function, but more as a family of different functions or constructs (Dempster, 1993; Harnishfeger, 1995; Nigg, 2000). In this thesis, we started from the taxonomy of Nigg (2000) and a latent variable analysis of Friedman and Miyake (2004). In both papers, it was pointed out that there were differences between various forms of inhibition while there might also be some correlations. We tried to find further behavioural evidence for the hypothesis that there might be a certain overlap between at least a subset of inhibitory functions. In the paper of Nigg, the proposed taxonomy was not directly tested and the latent variable analysis of Friedman and Miyake is arbitrary in a sense that the three different inhibitory functions they used in their confirmatory factor analysis are arbitrary. Hence, our experiments can be considered as an extension of those two studies.

Our results with the stop signal task, and more specifically, the SSRT differences between conflict and non-conflict trials, largely mirrored the findings of Friedman and Miyake (2004). One of the main findings of Friedman and Miyake (2004) was that prepotent response inhibition and resistance to distractor interference were closely correlated. In Table 6.1, the tasks used by Friedman and Miyake are presented again; with in bold the tasks that we used.

Table 6.1: Three inhibition-related functions according to Friedman and Miyake²⁸ (2004), with the three tasks these authors used for each function (the tasks in bold are used in our studies)

Prepotent Response Inhibition
Antisaccade task (Hallet, 1978)
Stop signal task (Lappin & Eriksen, 1966; Logan & Cowan, 1984)
Stroop task (Stroop, 1935)
Resistance to Distractor Interference
Eriksen flanker task (Eriksen & Eriksen, 1974)
Word naming (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994)
Shape matching (DeSchepper & Treisman, 1996)
Resistance to Proactive Interference
Brown-Peterson variant (Kane & Engle, 2000)
AB-AC-AD (Rosen & Engle, 1998)
Cued recall (Tolan & Tehan, 1999)

²⁸ Note that Friedman and Miyake (2004) used the Stroop task to assess prepotent response inhibition, whereas the flanker task was used as an interference task. Although the Stroop effect is indeed due to an automatic reading tendency (and therefore prepotent), one could argue that the Stroop effect has more in common with the flanker task than with the antisaccade task or the stop signal task. For example, in the review article of MacLeod (1991), the flanker task was considered as a variant of the Stroop task, because of the fact that in both tasks, irrelevant distracting stimulus features interfere with the processing of the relevant feature.

Given the correlation between the flanker task and the stop signal task in the Friedman and Miyake study, it is not surprising that we found in our experiments that the stopping latencies in the stop task were influenced by the congruency of the trials in the flanker task.

However, Friedman and Miyake (2004) interpreted the correlation between prepotent response inhibition and resistance to distractor interference in terms of a shared mechanism responsible for the active maintenance of task goals in the face of distracting information of inappropriate response. Alternatively, we suggest that their findings can also be interpreted as evidence for a common inhibitory mechanism that selectively suppresses the distracting information or inappropriate responses. We already mentioned that performance in the stop signal task is also influenced by the antisaccade task which was also used by Friedman and Miyake (Logan & Irwin, 2000). Thus, despite this difference in theoretical explanations for the relation between inhibitory functions, using different methodologies (latent variable analysis and stop signal performance) led to similar results.

Furthermore, we did not only replicate the findings of Friedman and Miyake (2004) with regard to the relation between Prepotent Response Inhibition and Resistance to Distractor Interference. These authors also looked at the relation between those two inhibitory functions and other inhibitory paradigms or tasks such as the random number generation task, the negative priming paradigm, task switching ability and the reading span task. Here, we will only focus on the tasks that we used in our studies, namely negative priming and task switching. Friedman and Miyake (2004) found that Response-Distractor inhibition (the combination of prepotent response inhibition and resistance to distractor interference) was not correlated with negative priming whereas it did correlate with task switching ability. Again, this is also largely mirrored in our data. We did not find any effect of negative priming on response inhibition and at least for selective stopping, there was an effect of task switching for the SSRTs.

To summarize, the findings in our studies are to a large extent in line with the findings of Friedman and Miyake (2004) and with the proposals of

Nigg (2000). Our studies also fit in with recent findings in the domain of neurology and neuropsychology. Several neuroimaging studies demonstrated that also at a neuroanatomical level there might be an overlap between different inhibitory functions. It appears that certain brain regions are activated in different inhibitory tasks. Before we continue interpreting these findings, it is important to note that commonly activated brain regions can have at least three distinct reasons: (a) the different tasks might share cognitive operations in which the common region might be involved (the 'sharing view'), (b) the different tasks activate different subdivisions of the same region (the 'subdivision view') and (c) a particular brain region can be involved in different tasks but this does not necessarily mean that it does compute the same cognitive operation in both tasks (the 'network view'; Cabeza and Nyberg, 2002, cited in Derrfuss, Brass & von Cramon, 2004)

In other words, interpreting overlap of brain regions should be done with some caution. However, it can be very useful when it is done in combination with behavioural studies that also provide evidence for common or shared mechanisms. In fact, that is what we tried to do in our behavioural experiments and studies, and therefore, our results can be compared with neuroanatomical findings. Several brain imaging studies pointed out that there are certain brain regions that are activated in a whole range of inhibitory tasks, especially frontal regions. We already mentioned the study of Aron, Robbins and Poldrack (2004) in which it was stated, based on both imaging data and lesion studies, that the right inferior frontal cortex plays a key role in a variety of inhibitory tasks. For example, it was found that the amount of damage to the right inferior cortex correlated strongly with the SSRT in the stop signal task: More damage resulted in longer SSRTs (Aron, Fletcher, Bullmore, Sahakian & Robbins, 2003). Interestingly, the inferior frontal cortex is also activated in other tasks that we used in our studies like the flanker task (e.g., Bunge et al., 2002; Hazeltine, Poldrack, & Gabrieli, 2000) and the Stroop and Simon task (e.g., Peterson et al., 2002). Hence, our findings can be fitted in with what is previously found in neuroimaging studies.

Even though the right inferior cortex is considered to be the key region for inhibition, it is probably part of a broader network of prefrontal regions. As argued by Aron et al. (2004), the reason the same set of regions is activated (consisting of the dorsolateral prefrontal cortex, the anterior cingulate cortex and the inferior frontal cortex), is that all these regions contribute to optimal performance in a whole range of different cognitive tasks. Aron et al. (2004) hypothesized that the left-lateral prefrontal cortex maintains task goals and task sets, the anterior cingulate cortex (ACC) detects conflict when the stimulus does not match those goals, and right IFC suppresses the irrelevant response. Of course, this is only a subset of regions that contribute to optimal task performance in different inhibitory tasks. For example, we know that the ACC is only activated in case of response conflict and not in case of stimulus conflict (Milham et al., 2001; Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). Nonetheless, we have demonstrated that conflict detection also occurs in case of stimulus conflict. Another example is the important role of the basal ganglia in the stop signal task (e.g., Band & van Boxtel, 1999; Rieger, Gauggel, & Burmeister, 2003; van den Wildenberg et al., in press). In other words, although the right inferior cortex appears to be very important, this region is probably only part of a broader network responsible for various kinds of inhibition.

This brings us to the last point of this discussion: The implementation of inhibition in the broader domain of cognitive control and executive functioning. The last years a vast amount of neuroimaging and behavioural studies investigated the concept of cognitive control. Several theories were proposed in which inhibition is often considered as a fundamental and important function within the domain of cognitive control. For example, Miyake et al. (2000) argued that inhibition was one of the three 'core' executive functions ('shifting', 'updating' and 'inhibition'). These authors used a confirmatory factor analysis, and found moderate correlations between the three proposed executive functions. In a neuroimaging context, different inhibitory tasks like the Stroop task and the flanker task are often used to assess cognitive control (for a review, see Aron et al., 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). In this

context, researchers are mainly interested in the role of different brain areas responsible for cognitive control, and use inhibition as a marker for cognitive control. Nonetheless, in those neuroimaging studies, the key assumption is that cognitive control involved in decision making can be considered as a aggregation of different processes, such as goal-directed action selection, response activation and inhibition, performance monitoring, and reward-based learning (Ridderinkhof, van den Wildenberg, et al., 2004).

Actually, we can conclude this discussion with (a part of) the citation that we used at the beginning of this doctoral thesis: *'The ability to suppress (...) is essential for normal thinking processes and, ultimately, for successful living (Garavan, Ross, & Stein, 1999)'*.

UNRESOLVED ISSUES AND FUTURE DIRECTIONS

In the final part of this chapter we will present some directions for further research. In this doctoral thesis, we stressed the fact that inhibition should be regarded as a family of inhibitory functions. Some of these functions are correlated with other functions, others are probably not correlated. We think that there are at least three different issues that deserve further research: (a) what determines the correlation between different inhibitory functions; (b) is there a link between within-trials and between-trial adjustments; and (c) how is stimulus conflict related to response conflict?

UNITY AND DIVERSITY: DETERMINANTS OF THE CORRELATION

Our studies fit in with the research that investigates the correlation between different inhibitory constructs. We focused on what different functions had in common. Conversely, there are also differences between different tasks and functions, suggesting diversity. In developmental and individual differences studies, it was demonstrated that behavioural inhibition and cognitive inhibition might be different psychological constructs (see Harnishfeger, 1995). For example, in the above mentioned

study of Kramer et al. (1994), not only the flanker task and the stop signal task were used, but a whole battery of inhibitory tasks. Actually, Kramer et al. were mainly interested in age-related differences in inhibitory tasks and they showed impairments for some of these tasks (e.g., the stop signal task) and not for other tasks (e.g., a flanker task).

Several explanations have already been offered for this pattern of non-correlations between different inhibitory tasks. Friedman and Miyake (2004) pointed out that problems with task purity, task reliability and construct validity made it difficult to interpret low or zero correlations. They argued that latent variable analysis alleviated these problems. But even when latent variable analysis was used, it appeared that Prepotent Response Inhibition and Resistance to Distractor Interference were not correlated with Resistance to PI. Friedman and Miyake (2004) suggested that this non-correlation in their study might be caused by two different factors. First of all, it could be the case that Resistance to PI is not an effortful form of inhibition. Secondly, the source of interference could be different. In the Response-Distractor inhibition tasks, the interference is due to external stimuli in the environment, which is not the case for Resistance to PI (Friedman & Miyake, 2004). In Chapter 3, it was also hypothesized that the source of interference might be of importance when we tried to explain why response inhibition is not influenced by the compatibility of the stimulus in a *pure* stimulus-response compatibility task. We argued that this was also possibly due to the source of the compatibility effect. In addition, in the negative priming study, we did not find any effect of negative priming on response inhibition. Since it was argued that in negative priming the source of interference is due to internal stimuli (mental representations and stimulus-response associations), it is not surprising that we did not find an interaction.

Therefore, we think that the source of the interference or conflict might indeed be an important factor in explaining the relation between different inhibitory functions. In a sense, this can be related to the distinction between the agents and the sites of inhibition (Band & van der Molen, 1999), and to the suggestion that a broader network of brain regions is responsible for cognitive control, and therefore inhibition (e.g., Aron et al., 2004;

Ridderinkhof, van den Wildenberg, et al., 2004). Future research will have to investigate whether this can explain why for example not all inhibitory functions correlate in the same way with each other and explain for example age differences. One hypothesis could be that most of the underlying inhibitory mechanisms in inhibitory tasks develop in the same way but that the implementation in the broader network differs.

COGNITIVE CONTROL AND INHIBITION: WITHIN- AND BETWEEN-TRIALS ADJUSTMENTS

A second issue concerns the relation between the within-trial and between-trial adjustments, and is probably the most difficult one to tackle. We already mentioned in the discussion of the second study of Chapter 2 that in fact, it could be the case that not conflict resolution but rather conflict detection interferes with stop signal inhibition. Performance monitoring is most likely present in both conflict trials and stop signal trials. As a result, it could be possible that the act of monitoring instead of the response to the monitoring signal (i.e., selective suppression or stop signal inhibition) is responsible for the found interactions. The problem here is that it is unclear at the moment how performance monitoring as suggested in for example the conflict monitoring theory (Botvinick et al., 2001; Botvinick, Cohen, & Carter, in press), can be implemented on a within-trial basis and whether or not the signal can be used to resolve response conflicts (Ridderinkhof, Ullsperger, et al., 2004). As pointed out by Ridderinkhof, it is difficult to disentangle the monitoring signal and the answer to this signal. Furthermore, the fact that the answer to a conflict situation happens at both a within-trial level (e.g., selective suppression of the irrelevant stimulus feature) and at a between-trial level (e.g., strategic adjustments), does not make it much easier. In fact, it could be the case that both types of adjustments are not that dissimilar. In general, between-trial adjustments concern the optimizing of pathways and the processing of the target-relevant information (Milham et al., 2001). But others added that the indirect route becomes suppressed after the detection of a (response) conflict. For example, Stoffels (1996) hypothesized a preset

suppression of the indirect route after an incompatible trial. Alternatively, Stürmer, Leuthold, Soetens, Schröter and Sommer (2002) argued that following a response conflict the transmission of the output of the indirect route to the motor execution system is blocked. Although this blocking hypothesis is still debated, it could be an interesting starting point for further investigation of the relation between within-trial and between-trial adjustments in conflict situations. To go even further, one could focus on how these adjustments are related to the concept of inhibition as assessed in a whole range of different tasks.

STIMULUS AND RESPONSE CONFLICT: MORE OF THE SAME?

One of the most important findings besides the interaction between response inhibition and selective suppression is that our results suggested that there is a close similarity between stimulus and response conflict. At the moment, little is known about stimulus conflict. Most researchers focused on response conflict and often, stimulus conflict is only included in the experiments to point out the differences with response conflict (like in the studies that focused on the contribution of the ACC in conflict detection). But more and more studies demonstrated that there might be an important similarity between stimulus conflict and response conflict (e.g., Liu et al., 2004). Our results with the stop signal paradigm suggest that the suppression mechanism that helps to resolve the response conflict could also help to resolve the stimulus conflict. In addition, we were able to demonstrate in the absence of stimulus-response repetitions that the stimulus conflict disappeared after a stimulus incongruent trial in a flanker task, suggesting top-down adjustments after the detection of stimulus conflict. On the one hand, it seems that the conflict detection is different for stimulus and response conflict. On the other hand, it is unknown whether the conflict resolution or conflict adaptation on a within-trial and between-trial basis (e.g., by means of selective suppression of the distracting stimulus feature) is similar or not. In the extended activation-suppression mechanism that we proposed, we argued that selective suppression could occur at any

processing stage from stimulus perception to response execution. However, the nature of selective suppression is still unclear. Again, this leads us back to the distinction between the agent and the site of inhibition: Is the agent of selective suppression in case of a stimulus conflict the same as the agent of selective suppression in case of a response conflict?

All in all, there is room for more research on what was once called at a lecture at our department '*the worst nightmare of cognitive psychologists*' (someone who probably wishes to remain anonymous).

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