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Perspectives on stopping behavior : process analyses of stop-signal inhibition

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1.1 Defining response inhibition as stopping behavior

The other day, I was stirring my macaroni with my right hand, while a kitchen towel kept me from burning my left hand on the hot handle. Suddenly, the towel caught fire as it contacted the gas flame. From there, it all went very quickly; I immediately let go of the spoon, waved the burning towel about before throwing it into the sink and soaking it with water. The whole scene was over in about 3 seconds. This example illustrates the importance in every day life of the ability to stop actions quickly. The stopping of ongoing behavior is the first step towards new courses of action. In the kitchen example, the stirring of the macaroni was abandoned rapidly and replaced by more appropriate behavior aimed at extinguishing the burning towel. Inhibitory control is a prerequisite for 'top-down' cognitive control. Goal-directed behavior would be impossible without the ability to dynamically adjust one's actions to the ever-changing environmental demands.

This thesis is concerned with the analysis of the mental processes involved in inhibitory motor control, the ability in humans to abort ongoing actions. It investigates the cognitive processes involved in stopping and how these processes relate to environmental demands. Response inhibition can be interpreted as an internally generated form of extreme executive control that can either be triggered by external demanding signals from the environment but can also be initiated voluntarily. For instance, you can stop reading this introduction once you decide that other things deserve priority. In the interest of clarity, I cite an unambiguous definition of inhibition to set the stage.

"By inhibition we mean the arrest of the functions of a structure or organ, by the action upon it of another, while its power to execute those functions is still retained, and can be manifested as soon as the restraining power is removed."

Lauder T. Burton, On the Nature of Inhibition (cited in Smith, 1992).

When trying to grasp the processing properties of stopping, the empirical investigator is confronted with the obvious problem that there is nothing to observe when stopping was successful. We can, for example, time the latency of a button-press response, but how could we determine the speed of stopping a button-press response? To broaden understanding of inhibitory motor control in the natural environment, investigators have developed a controlled artificial environment: *the stop-signal paradigm*. The stop-signal paradigm provides a useful tool to investigate the covert cognitive processes that constitute inhibitory motor control (Logan & Cowan, 1984; for the standard work on stop-signal inhibition, see Logan, 1994: On the ability to inhibit thought and action; A users' guide to the stop-signal paradigm). I will first describe the stop-signal paradigm; one of the tools used by experimental psychologists to measure inhibitory control. I present a selective overview of the literature on stopping, summarize the data obtained with the stop-signal task, and explain the implications and predictions of the race model, which is commonly used to describe behavior in the stop-signal paradigm. Finally, I will formulate some questions that remain unanswered and conclude this general introduction with a broad outline of this thesis.

1.2 Investigating stopping with the stop-signal paradigm

In the stop-signal paradigm, the participant usually performs a computerized choice reaction time (RT) task that requires him or her to discriminate between two visual stimuli. For example, subjects may be instructed to press a response button with the left index finger to the presentation of an 'X' and to press another button with the right index finger to an 'O' stimulus. This primary RT task is referred to as the *go task* and 'X' and 'O' stimuli are referred to as *go signals*. During the execution of the go task, a stop signal (usually a brief tone) is presented occasionally and unpredictably in a proportion, say 25%, of the trials. These trials are called *stop-signal trials*. The subject is instructed to put an effort into canceling his or her pending button-press response to the go stimulus when faced with a stop signal. The stop-signal delay, that is the interval between the presentation of the go signal and the onset of the stop signal, is under experimental control. If the interval between the go-signal and the stop-signal is consistently short, say 10 ms, then subjects will inhibit all the time. Similarly, if stop-signal delay is relatively long, subjects will respond to a large proportion of the stop-signal trials. Presenting subjects with only one fixed stop-signal delay on stop-signal trials would have the obvious drawback that subjects could postpone their response to the go signal, awaiting a possible stop signal (Lappin & Eriksen, 1966; Logan, 1981). So, in order to avoid subjects adopting undesirable strategies, stop-signal delays should be sufficiently variable to be unpredictable for the subject.

A useful tool to achieve 50% successful inhibits is the staircase-tracking algorithm (Levitt, 1971; Logan, Schachar, & Tannock, 1997; Osman, Kornblum, & Meyer, 1986). This algorithm adaptively adjusts the timing of the stop-signal, depending on the subject's behavior on the previous stop trial. After a successfully inhibited stop trial, stop-signal delay in the next stop-signal trial is increased, thus biasing the chances of responding. Conversely, stop-signal delay is decreased in the next stop-signal trial if the subject responded, thus increasing the chances of successful inhibition. Application of this procedure should theoretically result in stopping delays that are distributed around the median of the go distribution. A clear advantage of this tracking procedure is that it takes into account inter- as well as intra-individual differences in reaction time to go signals. Simulation results indicate that tracking algorithms targeting at inhibition ratios of about 50% have clear advantages over other tracking procedures (Band, van der Molen, & Logan, 2003).

1.3 The horse-race model and its assumptions

Behavior in the stop-signal task has been conceptualized as depending on the outcome of a race between go and stopping processes (Lappin & Eriksen, 1966; Logan, 1981; Ollman, 1973; Osman et al., 1986; Vince, 1948). The processes involved in the go task include stimulus recognition ('X' or 'O?'), response choice ('left' or 'right?'), and the preparation and actual execution of the button-press response. The stop process includes the detection of the stop signal and the abortion of the response. If the go process wins this race, then the go response will be executed despite the occurrence of a stop signal. Alternatively, if the stopping processes finish first, then the go response will be successfully withheld. The *horse-race model* provides an accurate description of the behavioral data observed in the stop task. One of

the virtues of the race model, as formulated by Logan and Cowan (1984), is that, based on few formal assumptions, it allows for calculating the latency of the stop processes, that is, the covert *stop-signal reaction time* (SSRT). Before I go into the actual procedure to estimate SSRT in the stop task, I will first describe the assumptions that underlie the horse-race model.

A major proposition of the race model holds that the go and stop processes are independent (Logan, 1994; Logan & Cowan, 1984). The assumptions of independence concern context independence and stochastic independence. Context independence means that the latency of primary-task processing is not affected by the presence of stop processes, and vice versa. Stochastic independence implies that the latencies of go and stopping processes are not correlated. It is argued that if both these aspects of independence are met, the distribution of RTs on go trials represents the distribution of latencies of go processes on trials with a stop signal. Mean reaction times on stop-signal trials that escape inhibition (i.e., *signal-respond RTs*) can be predicted from the proportion of signal-respond trials and the go-signal reaction time distribution (see procedure described in estimating stop-signal reaction time).

Violations of stochastic independence, such as a positive correlation between go RT and SSRT, are thought to increase the difference between observed RT and predicted RT on stop-signal trials (De Jong, Coles, Logan, & Gratton, 1990; Jennings, van der Molen, Brock, & Somsen, 1992; Logan & Cowan, 1984). Large discrepancies between observed and predicted signal-respond RTs have been taken to suggest a poor fit of the horse-race model due to violations of the assumption of independence between go and stopping processes. However, extensive simulations by Band and colleagues (Band et al., 2003) have indicated that a mismatch between observed and predicted signal-respond RT is not a valid test of the independence assumption. Their results showed that SSRT estimates were relatively accurate despite violations of the independence assumption, provided that certain conditions were met (such as the use of a stop-signal tracking algorithm, which will be described later).

The assumption that the latency of the stop process is constant is another proposition of the race model. The notion of an invariant stop latency facilitates the estimation procedure of SSRT. However, as for probably any other mental process, it is quite unlikely that SSRT has a variance of zero. The method presented by Logan and Cowan (1984) that treats the inhibition function as a distribution does not require assuming constant SSRT. Also, the method used by Logan et al. (1997), and Williams, Ponesse, Schachar, Logan, and Tannock (1999), that involves using the tracking algorithm to find the delay at which subjects inhibit 50% of the time and then subtracting mean delay from mean go RT does not assume that SSRT is a constant. Band et al. (2003) showed that violations of the proposition of invariant stopping latency increase the difference between observed and predicted signal-respond RTs, even when the go and stop processes were stochastically independent. The simulation studies further indicate that estimates of mean SSRT are not compromised when stopping latencies are variable.

Taken together, the race model is quite robust to violations of assumptions of independence and constant stopping latency. Minor violations of these assumptions do not necessarily result in unreliable estimates of SSRT (see Band et al. (2003) for extensive stimulation of the stop-signal paradigm).

1.4 Estimating stop-signal reaction time (SSRT)

One of the merits of the horse-race model is that it allows the estimation of the internal response to the stop signal; SSRT (Logan & Cowan, 1984; Logan, 1994). Following the horse-race model's assumptions outlined above, the RT distribution of the go process is the same whether or not a stop signal is presented. This implies that the left side of the distribution of RTs on go-signal trials, representing fast RTs, matches the distribution of RTs on stop-signal trials that escape inhibition (i.e., signal-respond trials). A graphical representation of a hypothetical distribution of go-signal RTs is presented in Figure 1.1.

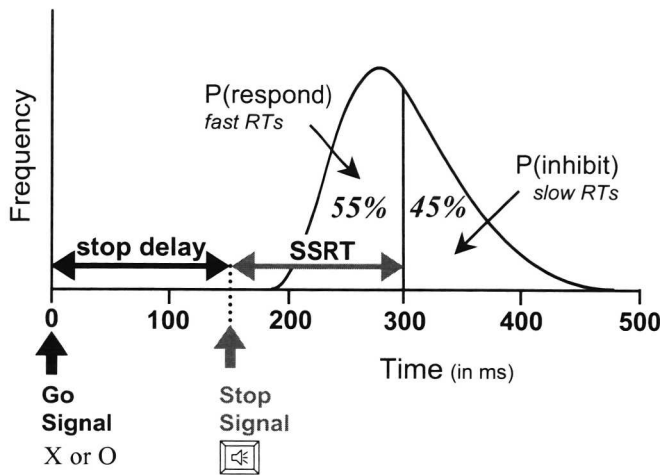


Figure 1.1: Diagram of the horse-race model. Stop-signal reaction time (SSRT) is inferred from the distribution of go-signal RTs (i.e., trials without a stop signal), the probability of inhibition, $P(\text{inhibit})$, and stop-signal delay.

The finish time of the stop process can be estimated from the observed go-signal RT distribution and the rate of successful stopping. The finishing time is represented in Figure 1.1 as the RT associated with the line that splits the RT distribution into a fast and a slow part. The go responses in the slow part, $P(\text{inhibit})$, will be outrun by the stop process and will therefore lose the race and get inhibited (signal-inhibit trials). Fast go responses, $P(\text{respond})$, will beat the stop process and run till response completion (signal-respond trials).

As can be seen in Figure 1.1, it turned out that subjects were able to inhibit their go responses successfully on 27 of 60 stop trials. Response ratio is then 55%, so the finish time of the stop process is on average equal to the go-RT value that goes with the 55-th percentile in the distribution. This leaves us with the finish time of the stopping process bisecting the distribution curve into fast signal-respond and slower signal-inhibit trials. The start of the stop process is under experimental control by the stop-signal delay, the timing of the stop-signal vis-à-vis the go signal. Finally, mean stop-signal delay is subtracted from the finish RT to

obtain an estimate of stopping latency (for a detailed exposition of alternative procedures to calculate stopping latencies see Logan (1994) and Logan & Cowan (1984), see also Band et al. (2003).

1.5 A selective review of stop-signal studies

Since its introduction, the stop-signal paradigm has served experimenters well and stop latency has often been used as an index of inhibitory control. It has turned out that healthy young adults are able to stop whatever they are doing in about 200 to 250 ms, indicative of a very close control over their actions. Among the various responses whose stopping properties have been investigated are manual responses (e.g., Logan, 1981), speech (Ladefoged, Silverstein, & Papcun, 1973), typing (Logan, 1982; Long, 1976; Rabbit, 1978), foot movements (De Jong, Coles, & Logan, 1995), and eye movements (Hanes & Carpenter, 1999; Logan & Irwin, 2000).

Like most - if not all - cognitive operations, stopping abilities appear to be subject to age-related changes across the life span. Administering the stop task to children has indicated that stopping becomes faster with increasing age throughout childhood (Bedard et al., 2002; Christ, White, Mandernach, & Keys, 2001; Ridderinkhof, Band, & Logan, 1999; Williams et al., 1999). Other developmental studies, however, failed to demonstrate systematic age-related changes, which is most likely due to a lack of statistical power (e.g., Band, van der Molen, Overtom, & Verbaten, 2000; Jennings, van der Molen, Pelham, Brock, & Hoza, 1997; Oosterlaan, 1996; Schachar & Logan, 1990; see also Williams et al., 1999). Indeed, those studies that did report an age-related increase in the ability to inhibit used larger samples or based their estimates of stopping latencies on a larger number of trials (for recommendations regarding optimizing the design of the stop-task, see Band et al., 2003).

Studies that have used a tracking algorithm for stop-signal presentation and have included adequate numbers of subjects and trials (according to the recommendations formulated by Band et al., 2003) yield consistent stop results. Williams et al. (1999) for example reported a significant age-related change in stopping speed in childhood and in older adulthood that was distinct from the age-related change in response speed. The stopping latencies reported by Williams decrease from 274 ms for 7-year-olds and 223 ms for 10-year-olds to 198 ms for 15-year olds and 209 ms for young adults. The speed of stopping decreased from mid-adulthood (210 ms) to 213 ms in older adulthood, and 230 ms in elderly (see also Kramer et al., 1994).

The stop-signal paradigm has also proven to be useful for examining individual differences in the ability to inhibit and inhibitory deficits. Adults that were characterized as impulsive on the basis of their scores on an impulsivity questionnaire (i.e., the Eysenck Personality Inventory) exhibited longer stopping latencies than non-impulsive controls (Logan et al., 1997). Although stopping latencies were longer in hyperactive children, these children displayed no deficiency in detecting the stop signal (Schachar & Logan, 1990). The observation that responses to go signals did not vary with impulsivity scores supports the notion that the ability to inhibit responses as reflected by SSRT can be used as an operationalization of impulsivity and impulse control. Support for this conjecture has been derived from clinical applications of the stop-signal paradigm in children diagnosed with ADHD (Attention Deficit Hyperactivity Disorder). These children exhibited slower stopping latencies than children diagnosed with other psychopathologies and normal control children (Jennings et al., 1997;

Oosterlaan, Logan, & Sergeant, 1998; Oosterlaan & Sergeant, 1995; Overtom et al., 2002; Schachar & Logan, 1990; Schachar, Mota, Logan, Tannock, & Klim, 2000; Van der Schoot, Licht, Horsley, & Sergeant, 2000; for reviews of ADHD studies with the stop-signal paradigm see Nigg, 2001). Next to distinguishing between groups like ADHD versus non-pathological controls, SSRT has been reported to discriminate ADHD children tested under different conditions. Stopping latencies improved after administration of the stimulant drug Methylphenidate compared with administration of a placebo in children with ADHD (Tannock, Schachar, Carr, Chajczyk, & Logan, 1989). Others have reported negative effects of alcohol on stopping latency within the normal population (Mulvihill, Skilling, & Vogel-Sprott, 1987).

Over the years, the standard stop-signal paradigm has been extended to cover more subtle manifestations of inhibitory control. For example, the stop process has been made more complex at the perceptual end by requiring discrimination between two or more stop signals. Subjects could be instructed to inhibit the planned response to one stop signal (e.g., the high-pitched tone) but to not the other (e.g., the low-pitched tone) (Riegler, 1986, cited in Logan, 1994).

Recently, Bedard et al. (2002) investigated the development of selective inhibitory control by adding a second stop tone to the typical stop-signal task. Over 300 subjects in the range of 6 to 82 years of age were instructed to inhibit their response execution when presented with a valid stop-signal tone, and to continue to respond when presented with an invalid stop-signal tone. Again, like simple stopping, there was a marked development throughout the life span in the execution of go responses. Specifically, response speed increased throughout childhood, and gradually declined throughout adulthood (see also Cerella, 1990; Kail, 1991; 1993). More importantly, the developmental trends in selective inhibitory control were unique and differed from the developmental trends in simple inhibition obtained using standard stop-signal tasks (i.e., the abortion of all ongoing response activation, Bedard et al., 2002). This observation could be taken to suggest that separate modes or mechanisms underlie simple and selective inhibitory control (De Jong et al., 1990; Logan, 1994). The issue of distinct inhibition mechanisms for simple and selective inhibition has emerged from psychophysiological studies too and will be described below. Typically, selective stopping latencies are substantially longer than simple stopping latencies. Bedard et al. suggested that non-selective (simple) stopping parallels the simple or Donders A response. Likewise, selective ("to stop or not to stop") stopping corresponds to a classic Donders C response (go vs. nogo) (Logan, 1994).

Others have focused on the motor end of the stopping process by instructing subjects to stop one response (e.g., their right-hand response) to the stop signal but not the other (e.g., left-hand) response. Logan, Kantowitz, and Riegler (cited in Logan, 1994) used this type of selective stopping task. Again, selective stopping was accompanied by longer stop latencies, and the latencies increased with the number of alternative go responses. Interestingly, simple SSRTs did not vary much between tasks – one out of four possible go responses was inhibited as fast as one out of two possible go responses. Based on these observations, Logan et al. (1986) proposed two modes of inhibition – a global mode for the inhibition of all pending responses, and a local mode for the selective inhibition of a particular response.

1.6 On the nature of stopping

The stop-signal paradigm has provided us with the informative SSRT that represents the latency of the internally generated act of stopping control. The horse-race model accounts well for the observed behavioral data. Although the application of the stop-signal procedure sheds light on stopping efficiency - for instance it distinguishes between subgroups like ADHD children and controls or younger vs. older children - it does not provide a deeper understanding of the nature of inhibitory motor control. Like the go process, the stop process too has an onset (the stop signal) leading to an (inhibitory) response. Several investigators have focused on experimental manipulation of processing stages to identify the cognitive operations that constitute the go processes (Sanders, 1980; 1998; Sternberg 1969; for a review see Van der Molen, Bashore, Halliday, & Callaway, 1991). In his review article on stopping, Logan (1994) suggested two possible research strategies that may deepen our understanding on the nature of stopping processes.

First, Logan suggested to focus on the experimental design of the stop task and factorially combined stopping with experimental manipulations that draw upon a form of inhibitory control as well to learn more about stopping from the possible interaction patterns. Logan (1981), for example, observed that stopping latency is approximately equal in spatially compatible and incompatible responses (see Logan & Irwin 2000, for a recent replication). Apparently, stopping does not interact with the ability to resolve the conflict between the prepotent compatible response and the spatially incompatible response (e.g., Kornblum, Hasbroucq, & Osman, 1990). Others combined stopping with the inhibition of responses to target stimuli flanked by task-irrelevant distracters assigned to the same or to the opposite response (Kramer et al., 1994; Ridderinkhof et al., 1999). These investigators found that responses to targets flanked by incongruent distracters were more difficult to inhibit than responses to congruent displays. This pattern of results was taken to suggest that stopping and the need to inhibit the (incorrect) response to incongruent flankers compete for execution (cf. Ridderinkhof et al., 1999).

Second, Logan (1994) pointed to the use of psychophysiological measures to focus on the temporal dynamics of response activation and response inhibition. De Jong was the first to examine the temporal dynamics of inhibitory processing (De Jong et al., 1990; 1995). The lateralized readiness potential (LRP) in combination with electro-myographic (EMG) measures led De Jong and colleagues to propose two separate inhibitory mechanisms - a slower central cortical mechanism capable of selective inhibition and a peripherally operating mid-brain mechanism for fast simple stopping. The notion of a peripheral inhibition mechanism has been linked with results obtained from cardiac studies by Jennings et al. (1992). These researchers report that successful inhibition of a motor response was associated with heartbeat slowing (deceleration), whereas failed inhibitions were not. The fact that cardiac inhibition and motor inhibition interact has been interpreted to suggest that both are controlled in part by the same midbrain system.

However, based on a review of psychophysiological data in the stop-signal literature, Band and van Boxtel (1999) formulated an alternative interpretation of the neural mechanisms involved in stopping. Their main point was that a peripheral stop mechanism is incorrectly inferred from the psychophysiological data. As an alternative, Band and van Boxtel suggested a model, in which an integrated circuit of the prefrontal cortex and basal ganglia are candidate

agents of response inhibition, whereas possible effect sites of inhibition are the thalamus and motor cortex (Brunia, 1993; cf. Goldberg, 1985). This notion is in line with an extensive psychophysiological analysis of inhibitory motor control that included measures of brain activity, heart rate, muscle activity, response force, and respiratory cycle (Van Boxtel, van der Molen, Jennings, & Brunia, 2001).

The involvement of the prefrontal cortex in stopping has been indexed by a brain wave, called the N200. The N200 is a negative ERP (event-related potential) component that exhibits its maximum over the frontal cortex about 200-300 ms after the nogo signal in a go/nogo task. (Eimer 1993; Jodo & Kayama, 1992; Kok, 1986; Naito & Matsumura, 1994; 1996; Pfefferbaum, Ford, Weller, & Kopell, 1985; Van Boxtel et al., 2001). A persuasive argument for prefrontal involvement in stopping is provided by the observation that electrical stimulation of frontal cortex loci associated with the nogo potential (i.e., the dorsal bank of the principal sulcus and the rostroventral corner of the prefrontal region) during normal response activation suppresses the activity in the motor cortex, and hampers the production of an overt response in monkeys (Sasaki, Gemba, & Tsujimoto, 1989). Brain-imaging techniques (Pliszka, Liotti, & Woldorff, 2000; Rubia et al., 2001) and microelectrode studies (Kawashima et al., 1996; Sasaki & Gemba, 1986; Sasaki, Gemba, Nambu, & Matsuzaki, 1993) have also provided support for the prefrontal substrate of inhibitory processing.

Single-cell recordings in primates performing on a stop task provide a third approach towards a better understanding of the nature of inhibition. Hanes and colleagues recorded unit activity in the frontal eye fields during the countermanding of eye movements and identified single-cell signatures of inhibitory visuo-motor control (Hanes, Patterson, & Schall, 1998; see Logan & Irwin 2000, for a behavioral study comparing inhibitory control of eye and hand movements).

Taken together, clever factorial stop-signal designs, psychophysiological, and brain imaging assessments, and single-cell recordings have augmented performance indices of inhibitory processing and in doing so contributed considerably to our understanding of the nature of stopping.

1.7 Remaining questions and the outline of this thesis

Although there is ample literature addressing inhibitory control, some important questions still remain unanswered. One issue, which is the subject of Chapter 2, concerns the relation between the primary-task processes and stopping processes. De Jong et al. (1995, p. 507) recognized that the investigation of interactions between response readiness and response inhibition would be an interesting topic for further research. As outlined earlier, co-variation of go and stop processes might violate the assumption of independence. The goal of the study presented in Chapter 2 is to examine the stopping latency of motor responses executed during a state of reduced response readiness - a kind of inhibition that can be elicited by inserting nogo or catch signals into the primary-task trial series. A variant of the stop task was used to induce different levels of response readiness.

As often, the results that came from this work raised new questions. The study described in Chapter 3 was carried out at Tilburg University and focuses on the relation between different levels of response readiness and stopping using force dynamics of response activa-

tion and inhibition. The hypothesis was tested that low-probability responses are more difficult to stop, as these responses are more forceful than high-probability responses.

Chapter 4 presents a developmental investigation of simple (i.e., non-selective) and selective stopping by manipulating the motor end of inhibitory processing. Bedard et al. (2002) have reported on selective stopping, but focused on the perceptual end of stop-signal processing using two stop signals. Our study afforded a direct within-subject comparison of the ability to inhibit responses in a selective manner and in an 'all-or-none manner'. In addition, the response selection demands of the primary task were manipulated by varying spatial stimulus-response compatibility (SRC) to investigate whether the speed of selective inhibition is determined by the response that has to be stopped. Manipulations of SRC have been associated with slower responses. Earlier studies have reported that simple stopping latencies were not affected by SRC (Logan, 1981; Logan & Irwin, 2000). The current investigation is the first attempt to combine SRC and selective stopping.

To learn about the nature of stopping process, Chapters 5 and 6 list two experimental paradigms that have proven to be successful in elucidating the architecture of mental processes involved in speeded responding. These are the *Simon task* and the *additive factor method* (AFM). The assumption is tested that stop processes are quite similar in nature to go processes. Go signals require perceptual discrimination, translation into an appropriate action, and then the programming and unfolding of that action. Likewise, stop signals require perceptual discrimination, translation into an appropriate action (i.e., inhibition of ongoing responses), and then the programming and unfolding of that inhibitory action. This analogy provides us with a context in which the stop process can be studied in a fashion similar to the explorations of the go process. The experiments presented in Chapter 6 make use of the AFM, which has been used extensively to explore stages of go-signal processing. This methodology is used here to test the assumption that stop processes are quite similar in nature to go processes. In Chapter 5, the stop task is crossed with the Simon task. Efficient response processing in the Simon task has been formulated in terms of inhibition of the response activation associated with task-irrelevant features. By applying typical Simon-task manipulations to the processing of the stop signal, the nature of stopping processes is examined in detail. It will be argued that go and stop processes are similar in nature, at least to some extent.

In their review of the neurophysiological mechanisms involved in stopping, Band and van Boxtel (1999) have highlighted a plausible mechanism by which the prefrontal cortex and the basal ganglia might exert response inhibition. Many researchers have indicated the involvement of frontal brain areas in stopping control, but few have explored the role of the basal ganglia in inhibitory motor control directly. The study presented in Chapter 7 adopts a neurophysiological perspective to explore directly the role of basal ganglia, and the subthalamic nucleus in particular, in response inhibition. The experiment afforded a true *within-subject* comparison of stopping control in several ways. First, the patients that participated in this study have either been implanted with a high-frequency stimulation electrode in the subthalamic nucleus or the ventral intermedialis nucleus of the thalamus. Second, the stop task was administered twice – once with the specified brain areas being stimulated and once without stimulation, which afforded a direct examination of the effects of brain stimulation on stop performance.

Finally, Chapter 8 provides a selective overview of this thesis and a discussion of stop-signal inhibition from a more general perspective.

This thesis has led to the following list of references that is presented below to acknowledge the important contributions of the co-authors.

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