Verbruggen, F., & Logan, G. D. (2009). Automaticity of cognitive control: Goal priming in response-inhibition paradigms. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(5), 1381-8. doi:10.1037/a001664

'This article may not exactly replicate the final version published in the APA journal.

It is not the copy of record.'

Abstract

Response inhibition is a hallmark of cognitive control. An executive system inhibits responses by activating a stop goal when a stop signal is presented. The authors asked whether the stop goal could be primed by task-irrelevant information in stop-signal and go/no-go paradigms. In Experiment 1, the task-irrelevant primes 'GO', '###' or 'STOP' were presented in the go stimulus. Go performance was slower for 'STOP' than for '###' or 'GO'. This suggests that the stop goal was primed by task-irrelevant information. In Experiment 2, 'STOP' primed the stop goal only in conditions in which the goal was relevant to the task context. In Experiment 3, 'GO', '###' or 'STOP' were presented as stop signal. Stop performance was slower for 'GO' than for '###' or 'STOP'. These findings suggest that task goals can be primed, and that response inhibition and executive control can be influenced by automatic processing.

Cognitive control theories attribute flexible, goal-directed behavior to an executive system, which controls performance by intentionally activating goals and manipulating their activation (Logan & Gordon, 2001; Meyer & Kieras, 1997; Miller & Cohen, 2001; Unsworth & Engle, 2007). However, several lines of research suggest that task goals can be activated automatically and unintentionally by information in the task environment (Aarts, Gollwitzer, & Hassin, 2004; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trotschel, 2001; Shah, 2003). Furthermore, studies of automaticity and learning suggest that people can learn associations between stimuli and task goals over practice, leading to automatic activation of task goals via retrieval of stimulus-task associations from memory (Koch & Allport, 2006; Verbruggen & Logan, 2008a; Waszak, Hommel, & Allport, 2003). Thus, cognitive control can be triggered in an intentional fashion (top-down) and in an unintentional, stimulus-driven fashion (bottom-up). In the present study, we examined the involvement of bottom-up control in response-inhibition paradigms.

The role of executive control in many paradigms is still debated (e.g. Logan & Bundesen, 2003; Mayr, Awh, & Laurey, 2003), but most researchers agree that executive control is involved in inhibiting a planned or ongoing motor response in response to changes in the environment or internal state (Aron, 2007; Logan & Cowan, 1984; Miyake et al., 2000; Verbruggen & Logan, 2008c). Response inhibition is often studied in the stop-signal paradigm (Logan & Cowan, 1984; for a review, see Verbruggen & Logan, 2008c). In this paradigm, subjects perform a go task, such as reporting the identity of a stimulus. Occasionally, a stop signal is presented, which instructs subjects to withhold the response on that trial. When a stop signal is presented, an executive system activates a stop goal; when the stop goal is activated, it inhibits the go goal and suppresses the go response (Logan & Cowan, 1984).

In three experiments, we attempted to prime the go and stop goals in the stop-signal paradigm and the related go/no-go paradigm. We presented primes that were associated with going and stopping, without specifying which go response had to be executed or stopped. This allowed us to distinguish

between goal priming and response priming. Goal priming is general, influencing all possible responses, whereas response priming is more specific, activating one response out of many (e.g., Stroop and flanker paradigms). If the stop goal is primed, then all go responses should be slowed; if the go goal is primed, then the stop–signal response should be slowed. We assumed that priming would be automatic and unintentional because the primes never predicted whether subjects needed to go or stop or which go response they should make (Tzelgov, 1997).

<div align="center">Experiment 1</div>

Experiment 1 tested the hypothesis that the go and stop goals could be primed by task-irrelevant information that appeared in the go stimulus in a stop-signal task (see Figure 1). Subjects were instructed to respond to the go stimulus, but to withhold the response when an auditory stop signal was presented. They were instructed to ignore the primes in the go stimulus. There were three primes: 'GO', '###' and 'STOP'. We included the neutral prime '###' to determine whether there was a priming cost (i.e, impairment of performance when the prime is incongruent with the relevant goal), a priming benefit (i.e., facilitation of performance when the prime is congruent with the relevant goal), or both. If 'STOP' primes the stop goal, then go performance should be impaired but stop performance should be facilitated; consequently, go reaction times (RTs) should be longer but stop-signal reaction times (i.e., the latency of the stop process; SSRT) should be shorter for 'STOP' than for '###'. If 'GO' primes the go goal, then go performance should be facilitated but stop performance should be impaired; consequently, RTs should be shorter but SSRTs should be longer for 'GO' than for '###'.

Method

Twenty students from Vanderbilt University participated for course credit. The experiment was run on a Pentium 4 PC running STOP-IT (Verbruggen, Logan, & Stevens, 2008). The stimuli were presented on a 19-inch cathode ray tube monitor. The go task was to respond as quickly and accurately as possible to a white filled square (25 x 25 mm) or circle (25 mm diameter) by pressing the 'Z' (with the left index

finger) or '/' (with the right index finger) keys of a QWERTY keyboard, respectively. The stimuli were

presented centrally on a black background. There were three primes: 'GO' (in green; 12 x 7 mm), '###'

(in blue; 18 x 7 mm), and 'STOP' (in red; 24 x 7 mm). The primes were presented in the go stimuli and

occurred with equal probability. Subjects were instructed to ignore the primes.

On 25% of the trials, an auditory stop signal (750 Hz, 80dB, 75 ms) was presented through closed

headphones (Sennheiser eH150). Stop-signal delay (SSD) was initially set at 250 ms and continually

adjusted according to a tracking procedure to obtain a probability of stopping of .50. Each time a subject

responded on a signal trial, SSD decreased by 50 ms; each time a subject inhibited successfully, SSD

increased by 50 ms. We used separate tracking procedures for the three primes. Subjects were informed

about the tracking procedure and they were told not to wait for a stop signal to occur.

The experiment started with a practice block of 32 trials, followed by 12 experimental blocks of

72 trials. Trial course and duration of time intervals are depicted in Figure 1.

Results and Discussion

Means of go and stop performance appear in Tables 1 and 2, respectively. We excluded no-signal trials

that followed a signal trial because go performance is often influenced by a stop signal on the previous

trial (Rieger & Gauggel, 1999; Verbruggen, Logan, Liefooghe, & Vandierendonck, 2008). Mean go RTs for

correct trials were calculated after exclusion of trials that followed a go error[1]. For every prime, SSRT

was calculated by subtracting mean SSD from mean RT of all no-signal trials (Logan, Schachar, &

Tannock, 1997; Verbruggen & Logan, 2009). Go RT and SSRT were analyzed by means of separate

repeated measures ANOVAs with prime (GO, ###, or STOP) as within-subjects factor. Go errors and

number of missed responses on go trials were low and were not further analyzed.

As can be seen in Table 3, go RT on no-signal trials was significantly longer for 'STOP' than for

'###'. There was no reliable difference between '###' and 'GO'. This suggests there was a priming cost

but no priming benefit in the go task. There was no significant effect of prime on SSRT, $F(2,38) > 1.7$, but

we observed numerical differences between the neutral prime and the other primes. Unlike go RTs, SSRTs need to be estimated; consequently, SSRTs tend to be more unstable than RTs. Closer inspection of the SSRT data showed that SSRT differences were inconsistent across subjects. Possibly, we did not find a consistent priming effect for stopping because the prime was part of the go stimulus and not part of the stop signal. We tested this hypothesis in Experiment 3.

<div align="center">Experiment 2</div>

In Experiment 2, we asked whether priming of the stop goal depended on the task context. Bargh et al. (2001) showed that goal priming did not require an intentionally activated goal to operate on, suggesting that goals could be primed when they were not immediately relevant to the task context. To test the importance of task context for priming the stop goal, we compared priming from 'STOP' in conditions in which the stop goal was and was not relevant to the task context. If the stop goal can be primed only when it is relevant to the task context, then we should observe goal priming only in conditions in which subjects were instructed to stop occasionally (making the stop goal relevant to the task context). If the stop goal can be primed when it is not relevant to the task context, then we should observe goal priming in conditions in which subjects were instructed to go on all trials (making the stop goal irrelevant to the task context).

There were three conditions: a stop-signal condition, a go-only condition, and a go/no-go condition. The *stop-signal condition* was similar to Experiment 1, in which the stop goal was relevant to the task context. In the *go-only* condition, no stop signals were presented so the stop goal was not relevant to the task context. If goal priming occurs only when the goal is relevant to the task context, then the 'STOP' prime should impair go performance in the stop condition but not in the go-only condition. However, go RTs are generally faster in go-only tasks than in stop-signal tasks (Verbruggen, & Logan, in press), so goal priming may fail because there is not enough time for it to affect go performance (Logan, 1980). Therefore, we included a go/no-go condition, in which subjects were

instructed to respond when a go stimulus (e.g., a square) was presented and not to respond when a no-go stimulus (e.g., a circle) was presented. Many researchers assume that no-go stimuli require response inhibition, although inhibition demands may be lower than in the stop-signal paradigm (Rubia et al., 2001; Verbruggen & Logan, 2008a). Go RT is typically faster in go/no-go conditions than in go-only conditions (Donders, 1868/1969), so if goal priming depends on response speed, then we should see no goal priming in the go/no-go condition and the go-only condition because there is not enough time for goals to influence go processing. However, if goal priming depends on the relevance of the stop goal to the task context, then we should see goal priming in the go/no-go condition but not in the go-only condition.

Method

Sixty students from Vanderbilt University participated for course credit. Twenty subjects were assigned to each condition. Apparatus, stimuli and procedure were similar to Experiment 1, except for the following. In the go-only condition, 100% of the trials were go trials. In the go/no-go condition, 50% of the trials were go trials, on which subjects had to press the space bar; 50% were no-go trials, on which they had to withhold the response. For half of the subjects, a square was the go stimulus and a circle was the no-go stimulus. For the other half of the subjects, this mapping was reversed. No auditory stop signals were presented in the go-only and go/no-go conditions.

For each condition, 'GO' was presented on half of the trials; 'STOP' was presented on the other half of the trials. Each condition started with a practice block of 32 trials, followed by 10 experimental blocks of 64 trials.

Results and Discussion

Means appear in Tables 1 and 2, and were analyzed by means of 3 (condition: stop, go-only, no-go) x 2 (prime: GO or STOP) mixed ANOVA. We used the same exclusion criteria as for Experiment 1. We found that RTs were longer for 'STOP' than for 'GO' in the stop-signal condition and the go/no-go condition but

not in the go-only condition (Tables 1 and 3). This conclusion was supported by a significant interaction between condition and prime, and suggests that priming is contextually dependent. Based on the findings of Experiment 1, we argue that the RT difference between 'STOP' and 'GO' reflects a priming cost due to priming the stop goal; Experiment 2 demonstrates that this priming only occurred when the stop goal is relevant to the task context. The interaction between priming and context also demonstrates that the meaning of the primes was important, and that the observed priming effects were not simply due to perceptual factors, which were constant across the three conditions.

There were overall RT differences between conditions: Go RT was longer in the stop-signal condition than in the go-only condition, and was longer in the go-only condition than in the go/no-go condition (Tables 1 and 3). The overall differences dissociate processing speed from goal priming: priming was observed when performance was slowest (stop-signal) and fastest (go/no-go) but not when performance was intermediate (go-only). The dissociation between processing speed and goal priming was further supported by an analysis of RT distributions (see Figure 3). For every condition and prime, we calculated 4 sample quantiles (Ratcliff, 1979) and reanalyzed RTs by means of a mixed ANOVA with prime, condition and quantile as factors. We replicated the findings reported in Table 3. Importantly, the priming effect and the interaction between priming and condition were not influenced by quantile; both $Fs < 1$. This supports the conclusion that the priming effect did not depend on response speed.

In the stop-signal condition, SSRT was similar for GO- and STOP-prime trials, $F < 1$. In the go/no-go condition, the probability of responding on no-go trials was comparable for GO- and STOP-prime trials, $F(1,19) = 2.6$, $p > .12$. These findings suggest that stop performance was not influenced by the primes.

<center>Experiment 3</center>

In Experiments 1 and 2, we found that going was influenced by the primes but stopping was not. In Experiments 1 and 2, the prime and the go stimulus were integrated (i.e., they appeared in the same

modality at the same location), but the primes and the stop signals were not (i.e., they appeared in different modalities)[2]. Several studies demonstrated that non-integrated primes produce less interference than integrated primes (for a review, see Macleod, 1991). Therefore, in Experiment 3, we presented the stimuli 'GO,' '###', or 'STOP' as stop signals in a stop-signal task (see Figure 2) to increase the likelihood that goal priming would influence the stop process. Subjects were told to inhibit the go response whenever any of these stimuli appeared. If the meaning of the stop signals activates task goals, then SSRT should be longer for 'GO' than for '###' and 'STOP'. If stop performance is somehow impervious to priming, then SSRT should be similar for 'GO', '###' and 'STOP'. As in previous experiments, subjects discriminated shapes in the go task.

The stop signals in Experiment 3 varied in size as well as identity. Perceptual factors can influence SSRT (Cavina-Pratesi, Bricolo, Prior, & Marzi, 2001; Morein-Zamir & Kingstone, 2006), so SSRT may be longer for shorter stop signals (GO) than for longer stop signals (### or STOP). To examine the effects of stop-signal length (i.e, the number of characters), we included a simple detection block at the end of the experiment. On every trial, 'GO', '###', or 'STOP' was presented and subjects were instructed to respond as quickly as possible to these stimuli by pressing the space bar. If 'GO' is detected more slowly than'###' or 'STOP', then SSRTs should be interpreted with caution.

Method

Twenty students from Vanderbilt University participated for monetary compensation. None of them participated in Experiments 1-2. Apparatus, stimuli and procedure were similar to Experiment 1, except for the following. On go trials, a non-filled shape was presented (Figure 2). On 25% of the trials, a stop signal appeared in the shape. We used three stop signals (GO, ### and STOP), which occurred with equal probability. The shapes and the stop signals appeared in white on a black background. The experiment started with one practice block of 64 trials, followed by 12 experimental blocks of 72 trials.

At the end of the experiment, subjects performed a block of 120 detection trials. The stimuli were 'GO', '###' and 'STOP'. The stimuli occurred with equal probability and remained on the screen for 1,000 ms, regardless of RT. Subjects were instructed to press the space bar as quickly as possible when they detected the stimulus. ITI was drawn from an exponential distribution (mean = 1,000 ms; minimum = 100 ms, maximum = 3,000 ms), and varied randomly between trials.

Results and Discussion

Mean go RT was 441 ms; mean percentage of correct go responses was 98.5%. Means of stop performance appear in Table 2. SSRT was analyzed by means of a repeated measures ANOVA with stop signal (GO, ###, STOP) as a within-subjects factor (Table 3). SSRT was longer for 'GO' than for "###", suggesting that stop performance was impaired when the stop signal was associated with the incongruent go goal. There was no difference between '###' and 'STOP', suggesting that priming produced a cost but no benefit. In the detection condition, we found that detection RT was similar for all stimuli (GO = 299 ms, ### = 302 ms, STOP = 303 ms; $F < 1$), which suggests that the observed SSRT differences were not due to differences in the length of the stop signal. This conclusion is further supported by the data of a pilot experiment, in which we presented '##' (12 x 7 mm) and '####' (24 x 7 mm) as stop signals (number of signal trials per stop signal = 48; number of subjects = 20). We found that SSRT was similar for the two stop signals (## = 231 ms; #### = 228 ms), $F < 1$. This suggests that relatively small differences in stop-signal length do not influence stop performance much.

General Discussion

Response inhibition is considered to be a key component of cognitive control. In the present study, we asked whether response inhibition can be primed automatically by irrelevant information in the environment. Consistent with the automatic control hypothesis, we found that the go and stop goals

were activated automatically by primes. However, the effects were numerically small, and the differences could be due to a small number of subjects with large priming effects. To test this idea, we plotted the difference between 'STOP' and 'GO' for the stop-signal conditions of Experiments 1-3. As can be seen in Figure 4, the priming effects were highly consistent across subjects. Thus, the findings of the present study clearly support the idea that cognitive control can be triggered in a stimulus-driven (unintentional) fashion as well as in a top-down (intentional) fashion.

Task goals were primed by task-irrelevant information, but performance depended mainly on intentionally activated goals. On STOP-prime trials in Experiments 1-2, go RT was prolonged but subjects executed the go response on virtually all go trials (Table 1); similarly, on GO-prime trials in Experiment 3, SSRT was prolonged but the tracking procedure worked well and subjects stopped on approximately half of the stop-signal trials (Table 2). Thus, the automatically activated goals interfered with performance, but the intentionally activated goals determined whether subjects actually responded or stopped. More generally, these results suggest that response inhibition can rely on automatically activated task goals, but only in combination with intentionally activated goals. This is consistent with results from other studies of automaticity, which show that automatically-activated responses influence performance, even though subjects almost always execute the intentionally activated response (Logan, 1980; Tzelgov, Henik, & Leiser, 1990).

The results of Experiment 2 suggest that goal priming depended on the relevance of the task goal to the task context: We found that the stop goal was primed when it was relevant to the task context (i.e, in the stop-signal and go/no-go conditions), but not when it was irrelevant to the task context (i.e, in the choice condition). This is inconsistent with the finding that automatic goal priming does not require an intentionally activated goal to operate on (e.g., Bargh et al. , 2001), but is consistent with the finding that responses are primed automatically only by features that are important to the task context (Hommel, 1996; Logan & Etherton, 1994; but see Rubin & Koch, 2006). Baseline activation of

context-relevant goals may be higher than baseline activation of context-irrelevant goals. Consequently, the priming effects will be stronger when the goal is relevant to the task context than when it is irrelevant. An alternative idea is that subjects need to find a balance between goal shielding and flexibility when several task goals are relevant: goals must be shielded from irrelevant information, but irrelevant information must be processed to some degree to respond to changes in the environment (Goschke & Dreisbach, 2008). Thus, subjects may be more vulnerable to information in the environment in situations in which flexible behavior is required (like the stop-signal condition), leading to larger priming effects. In sum, our finding of goal priming in response inhibition paradigms is consistent with previous findings (e.g., Aarts et al., 2004; Bargh et al., 2001; Shah, 2003), although priming of the stop goal may depend more strongly on task context (cf. Bargh et al, 2001). Future research is needed to clarify further when goal priming needs an intentionally activated goal to act on.

Recent work suggests that goals can be activated automatically via the retrieval of learned stimulus-task associations in response-inhibition paradigms (Verbruggen & Logan, 2008a; Verbruggen & Logan, 2008b) and task-switching paradigms (Koch & Allport, 2006; Waszak et al., 2003). Similar priming effects have been observed when goal-relevant stimuli are presented subliminally, suggesting that goals can be activated unconsciously in the stop-signal paradigm (Van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, in press) and in the task-switching paradigm (Mattler, 2003). Consistent with the findings of the present study, these studies found that priming incongruent goals interfered with performance, but intentionally-activated goals determined which response was executed. The present results add to these findings by showing that goals can be activated automatically by pre-existing semantic associations between irrelevant information in the task environment and task goals.

The goal priming effects in the present experiments and previous ones can be explained in terms of a stochastic accumulator model in which evidence for each goal accumulates until it reaches a threshold (Logan, 1980; Ratcliff & Smith, 2004; see also Boucher, Palmeri, Logan, & Schall, 2007). The

higher the accumulation rate, the faster the threshold is reached. The accumulation rate depends primarily on the match between task-relevant stimuli and the intended goals, with higher rates for better matches. However, accumulation rate may also be influenced by the match between irrelevant stimuli and the intended goals: congruent stimuli increase accumulation rate (decreasing the time required to reach threshold), whereas incongruent stimuli decrease accumulation rate (increasing the time required to reach threshold; Logan, 1980). Two properties of this accumulator model are especially relevant to the present experiments. First, the effects of task-relevant stimuli on accumulation rate are greater than the effects of task-irrelevant stimuli, or subjects would always make errors on incongruent trials (Logan, 1980). This implies that intentionally-activated goals must have stronger effects than automatically-activated goals, as we suggested earlier. Second, the costs of incongruent primes on RT are greater than the benefits from congruent primes even if the effects on accumulation rate are the same. This is illustrated in Figure 5 which plots accumulation rates for congruent, neutral, and incongruent prime trials. We assume that congruent and incongruent primes change accumulation rate by the same amount but in different directions (congruent primes add X units; incongruent primes subtract X units). Thus, the angle between congruent and neutral is the same as the angle between neutral and incongruent. Nevertheless, when these accumulation rates project onto the threshold, the difference between congruent and neutral is much smaller than the difference between incongruent and neutral (Figure 5). If the change in accumulation rate is small, as it must have been in our experiments, we would observe no goal-priming benefits but significant goal-priming costs.

To conclude, previous studies showed that goal-directed actions can be started and guided to completion automatically by information in the task environment. The present study showed that inhibiting an ongoing action can also be guided automatically by irrelevant information in the task environment. We argue that executive control processes such as response inhibition can be triggered both in a top-down and a bottom-up fashion (also see Hassin, Aarts, Eitam, Custers, & Kleiman, 2009).

Stimulus-driven, bottom-up control reduces the need for voluntary, top-down decisions. Consequently,

automaticity and cognitive control should not be regarded as opposites, as they may go hand in hand in

many situations (e.g. Bargh & Chartrand, 1999; Logan, 1988).

References

Aarts, H., Gollwitzer, P.M., & Hassin, R.R. (2004). Goal contagion: Perceiving is for pursuing. *Journal of Personality and Social Psychology*, *87*, 23-37.

Aron, A.R. (2007). The neural basis of inhibition in cognitive control. *Neuroscientist*, *13*, 214-228.

Bargh, J.A., & Chartrand, T.L. (1999). The unbearable automaticity of being. *American Psychologist*, *54*, 462-479.

Bargh, J.A., Gollwitzer, P.M., Lee-Chai, A., Barndollar, K., & Trotschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. *Journal of Personality and Social Psychology*, *81*, 1014-1027.

Boucher, L., Palmeri, T.J., Logan, G.D., & Schall, J.D. (2007). Inhibitory control in mind and brain: An interactive race model of countermanding saccades. *Psychological Review, 114,* 376-397.

Cavina-Pratesi, C., Bricolo, E., Prior, M., & Marzi, C.A. (2001). Redundancy gain in the stop-signal paradigm: Implications for the locus of coactivation in simple reaction time. *Journal of Experimental Psychology-Human Perception and Performance*, *27*, 932-941.

Donders, F.C. (1868/1969). On the speed of mental processes. In W.G. Koster, Ed., *Attention and performance II* (412-431). Amsterdam: North-Holland. (Original work published in 1868)

Goschke, T., & Dreisbach, G. (2008). Conflict-triggered goal shielding: Response conflicts attenuate background monitoring for prospective memory cues. *Psychological Science*, *19*, 25-32.

Hassin, R.R., Aarts, H., Eitam, B., Custers, R., & Kleiman, T. (2009). Nonconscious goal pursuit and the effortful control of behavior. In E. Morsella, J.A. Bargh & P.M. Gollwitzer, Eds., *The Psychology of Action (Vol. 2)*. New York: Oxford University Press

Hommel, B. (1996). S-R compatibility effects without response uncertainty. *Quarterly Journal of Experimental Psychology Section*, 49A, 546-571.

Koch, I., & Allport, A. (2006). Cue-based preparation and stimulus-based priming of tasks in task switching. *Memory & Cognition*, *34*, 433-444.

Logan, G.D. (1980). Attention and automaticity in Stroop and priming Tasks: Theory and data. *Cognitive Psychology*, 12, 523-553.

Logan, G.D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*, 492-527.

Logan, G.D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 575-599.

Logan, G.D., & Cowan, W.B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*, 295-327.

Logan, G.D., & Etherton, J.L. (1994). What is learned in automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory and Cognition,20,* 1022-1050.

Logan, G.D., & Gordon, R.D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review*, *108*, 393-434.

Logan, G.D., Schachar, R.J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science* , *8*, 60-64.

Macleod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163-203.

Mattler, U. (2003). Priming of mental operations by masked stimuli. *Perception & Psychophysics*, *65*, 167-187.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience*, *6*, 450-452.

Meyer, D.E., & Kieras, D.E. (1997). A computational theory of executive cognitive processes and multiple-task performance. I. Basic mechanisms. *Psychological Review*, *104*, 3-65.

Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167-202.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49-100.

Morein-Zamir, S., & Kingstone, A. (2006). Fixation offset and stop signal intensity effects on saccadic countermanding: a crossmodal investigation. *Experimental Brain Research*, *175*, 453-462.

Ratcliff, R. (1979). Group reaction-time distributions and an analysis of distribution statistics. *Psychological Bulletin*, *86*, 446-461.

Ratcliff, R. & Smith, P.L. (2004). A comparison of sequential sampling models for two-choice reaction time. *Psychological Review*, *111*, 333-367.

Rieger, M., & Gauggel, S. (1999). Inhibitory after-effects in the stop signal paradigm. *British Journal of Psychology*, *90*, 509-518.

Rubia, K., Russell, T., Overmeyer, S., Brammer, M.J., Bullmore, E.T., Sharma, T., Simmons, A., Williams, S.C.R., Giampietro, V., Andrew, C.M., & Taylor, E. (2001). Mapping motor inhibition: Conjunctive brain activations across different versions of go/no-go and stop tasks. *Neuroimage*, *13*, 250-261.

Rubin, O., & Koch, I. (2006). Exogenous influences on task set activation in task switching. *Quarterly Journal of Experimental Psychology*, *59*, 1033-1046.

Shah, J. (2003). Automatic for the people: How representations of significant others implicitly affect goal pursuit. *Journal of Personality and Social Psychology*, *84*, 661-681.

Tzelgov, J. (1997). Specifying the relations between automaticity and consciousness: A theoretical note. *Consciousness and Cognition*, 6, 441-451.

Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. *Journal of Experimental Psychology: Learning Memory and Cognition*, 16, 760-771.

Unsworth, N., & Engle, R.W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*, 104-132.

Van Gaal, S., Ridderinkhof, K.R., van den Wildenberg, W.P.M., & Lamme, V. (in press). Dissociating consciousness from inhibitory control: Evidence for unconsciously triggered response inhibition in the stop-signal task. *Journal of Experimental Psychology: Human Perception and Performance*.

Verbruggen, F., & Logan, G.D. (2008a). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General*, *137*, 649-672.

Verbruggen, F., & Logan, G.D. (2008b). Long-term aftereffects of response inhibition: Memory retrieval, task goals, and cognitive control. *Journal of Experimental Psychology: Human Perception and Performance*, *34*, 1229-1235.

Verbruggen, F., & Logan, G.D. (2008c). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, *12*, 418-424.

Verbruggen, F., & Logan, G.D. (2009). Models of response inhibition in the stop-signal and stop-change paradigms. *Neuroscience & Biobehavioral Reviews*, 33, 647-661

Verbruggen, F., Logan, G.D., Liefooghe, B., & Vandierendonck, A. (2008). Short-term aftereffects of response inhibition: Repetition priming or between-trial control adjustments? *Journal of Experimental Psychology: Human Perception and Performance*, *34*, 413-426.

Verbruggen, F., Logan, G.D., & Stevens, M.A. (2008). STOP-IT: Windows executable software for the stop-signal paradigm. *Behavior Research Methods*, *40*, 479-483.

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic

stimulus - task bindings in task-shift costs. *Cognitive Psychology*, *46*, 361-413.

Acknowledgments

Footnotes

Footnote 1 (p. 5)

In additional analyses, we also excluded outlying RTs that were longer than mean + 2.5 standard

deviations for each trial type; similar results were found. In the analysis reported in the text, we did not

exclude outlying RTs.

Footnote 2 (p. 8)

In the go/no-go condition, the prime and no-go stimulus were integrated. However, we may not have

seen a priming effect on stopping because probability of responding on a no-go trial was generally very

low, which may have been due to the low inhibition demands.

Table 1: Means for go RT, percentage of go errors (i.e., erroneous choice response) and percentage of missed go responses for Experiment 1 and the three conditions (stop-signal, go-only, go/no-go) in Experiment 2, as a function of the prime (GO, STOP or ###).

	Experiment 1			Experiment 2					
				stop-signal		go-only		no-go	
	GO	###	STOP	GO	STOP	GO	STOP	GO	STOP
go RT	439	440	445	477	487	404	405	344	348
go error	3.2	3	3.3	2.2	2.5	2.3	2.4	-	-
go miss	0.4	0.3	0.5	0.1	0.2	0.0	0.1	0.0	0.1

Table 2: Means for the stop data as a function of the prime (Experiments 1-2) or stop signal (Experiment 3)

	Experiment 1			Experiment 2: stop-signal condition		Experiment 2: No-go condition		Experiment 3		
	GO	###	STOP	GO	STOP	GO	STOP	GO	###	STOP
p(r|s)	.51	.51	.51	.51	.50	.007	.013	.50	.50	.50
SSD	191	192	206	255	263	-	-	212	224	225
SSRT	255	246	255	233	233	-	-	232	219	219
SR-RT	402	396	400	428	440	-	-	399	398	401

Note: p(r|s) = the probability of responding on a signal trial or no-go trial; SR-RT = signal-respond reaction time. For signal-respond RT, we included only signal-respond trials that followed a correct no-signal trial and on which the executed response corresponded to the response expected on no-signal trials (i.e., 'Z' for square and '/' for circle). For signal-respond RT, none of the differences was significant (all ps > .13).

	df	*F*	*MSE*	*partial η²*
		Experiment 1: Global analysis go RT		
Prime	2, 38	4.2*	61	0.18
		Experiment 1: Planned comparisons go RT (prime word)		
GO vs. ###	1, 38	0.6	61	0.01
### vs. STOP	1, 38	4.1*	61	0.10
		Experiment 2: Global analysis go RT		
Prime	1, 57	19.6***	39	0.26
Condition	2, 57	20.5***	9,050	0.42
Prime x condition	2, 57	5.6**	39	0.16
		Experiment 2: Planned comparisons go RT (prime word)		
Stop-signal condition	1, 57	26.5***	39	0.32
Go-only condition	1, 57	0.3	39	0.00
Go/no-go condition	1, 57	3.9†	39	0.06
		Experiment 2: Planned comparisons go RT (condition)		
Stop-signal vs. go-only	1, 57	13.2**	9,050	0.19
Go-only vs. go/no-go	1, 57	7.5**	9,050	.12
		Experiment 3: Global analysis SSRT		
Stop signal	2,38	15.0**	73	.44
		Experiment 3: Planned comparisons SSRT (stop signal)		
GO vs. ###	1,38	20.6**	73	.35
### vs. STOP	1,38	0.1	73	.00

***$p < .001$, **$p < .01$, *$p < .05$, †$p = .05$

Table 3: Overview analyses for Experiments 1-3

Figure captions

Figure 1: Depiction of a trial course and the trial types in Experiment 1. All trials started with the presentation of a fixation cross, which was replaced by the stimulus after 500 ms. The stimulus remained on the screen for 1,500 ms, regardless of RT. The intertrial interval was 1,000 ms. On stop-signal trials, an auditory stop signal was presented for 75 ms after a variable delay (SSD).

Figure 2: Depiction of of a trial course and the trial types in Experiment 3. All trials started with the presentation of a fixation cross, which was replaced by the stimulus after 500 ms. The stimulus remained on the screen for 1,500 ms, regardless of RT. The intertrial interval was 1,000 ms. On stop-signal trials, a visual stop signal was presented after a variable delay (SSD).

Figure 3: reaction times for the 4 sample quantiles as a function condition and prime

Figure 4: The numerical difference between incongruent and congruent primes for the stop-signal conditions of Experiments 1-3. For each experiment, the difference scores are ordered (smallest effect sizes on the left, largest effect sizes in the right).

Figure 5: Depiction of the stochastic accumulator account of goal priming. Activation begins when a stimulus is presented and accumulates toward a threshold at a constant rate. A goal is selected when activation reaches the threshold. Finishing-time distributions are plotted as the points at which activation reaches the threshold for each prime type. The sloping lines represent the mean accumulation of activation for congruent, neutral, and incongruent prime trials.
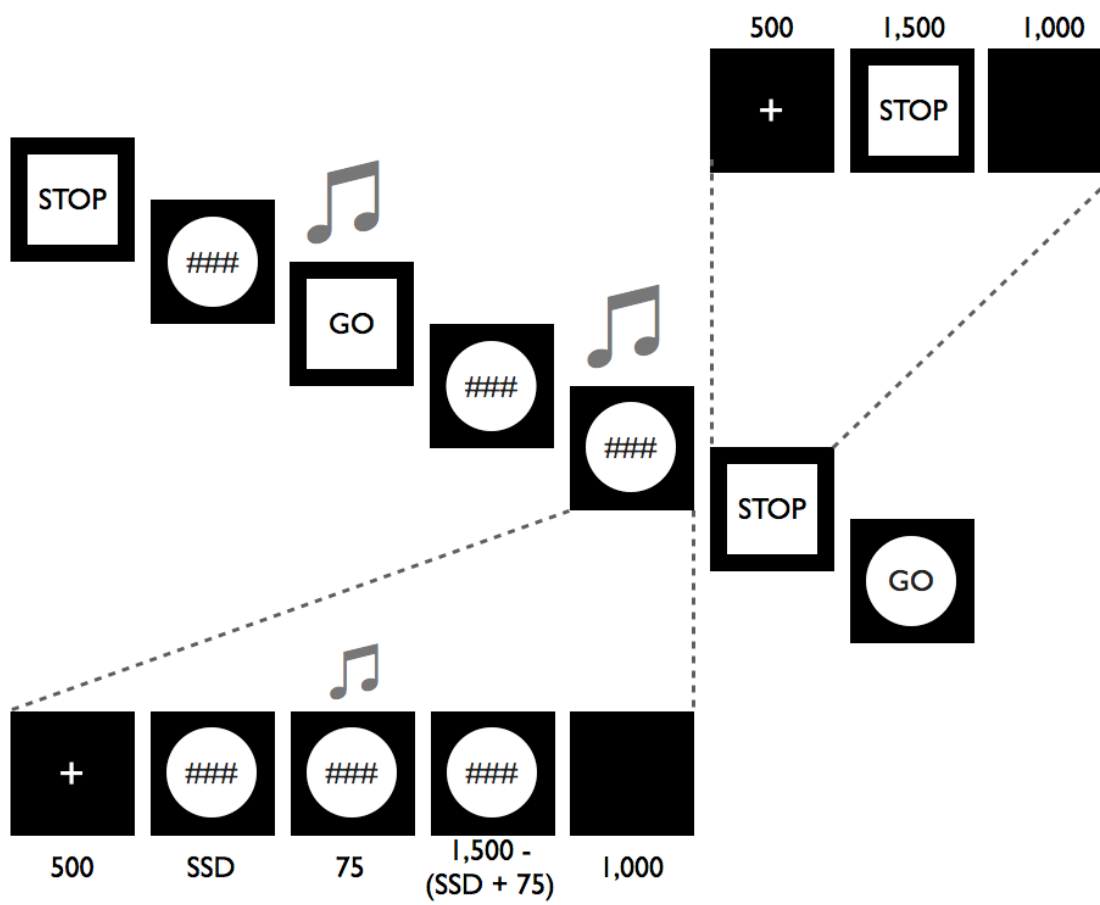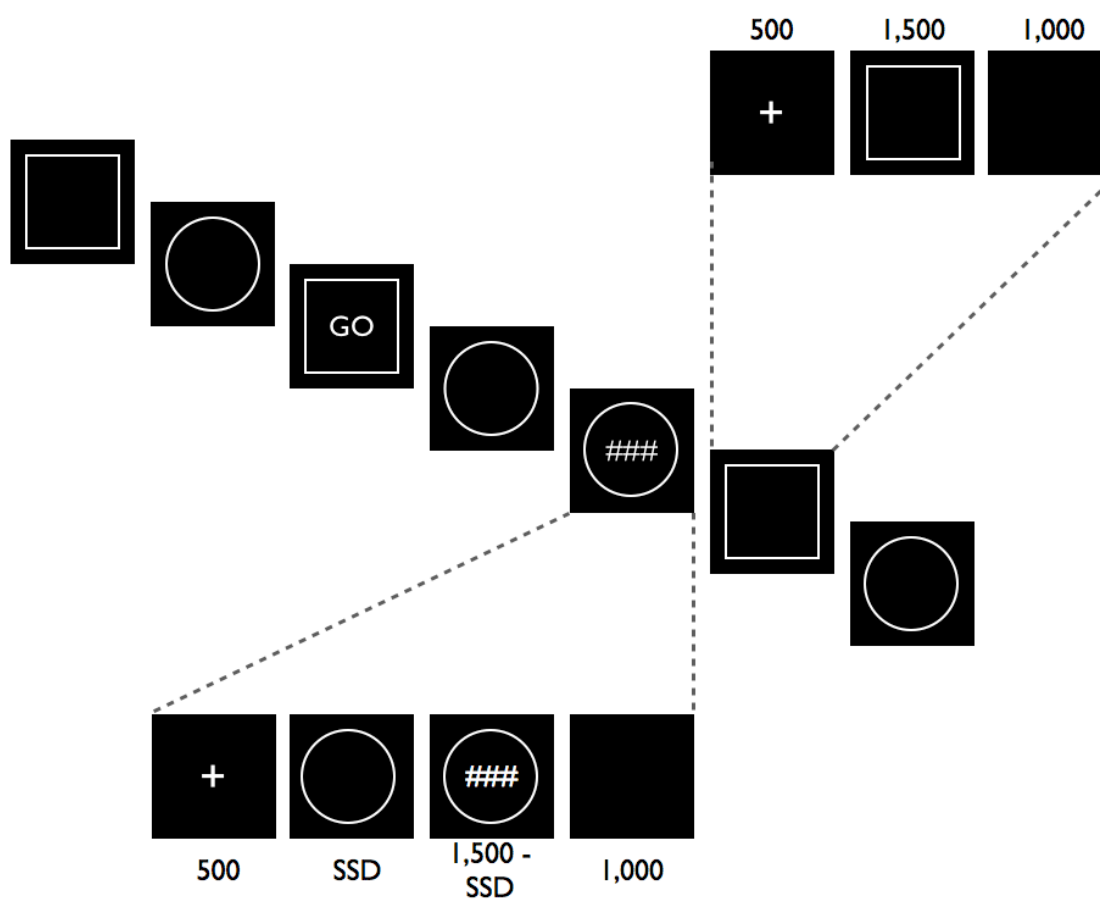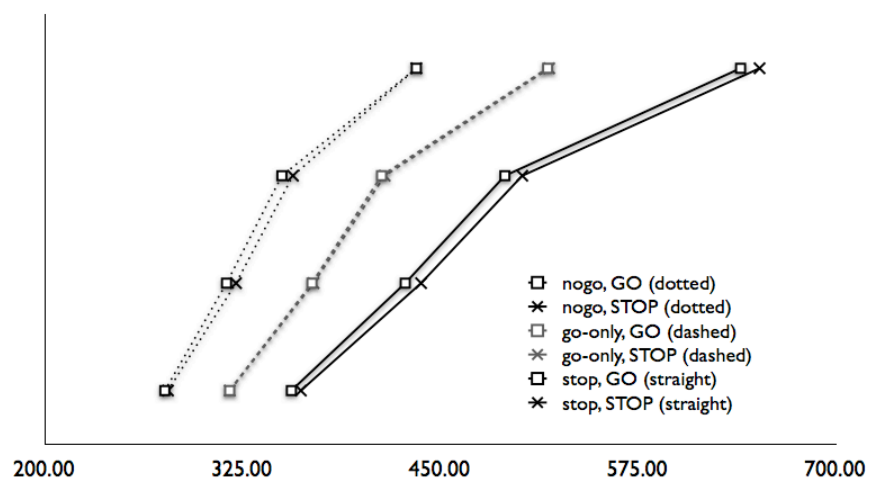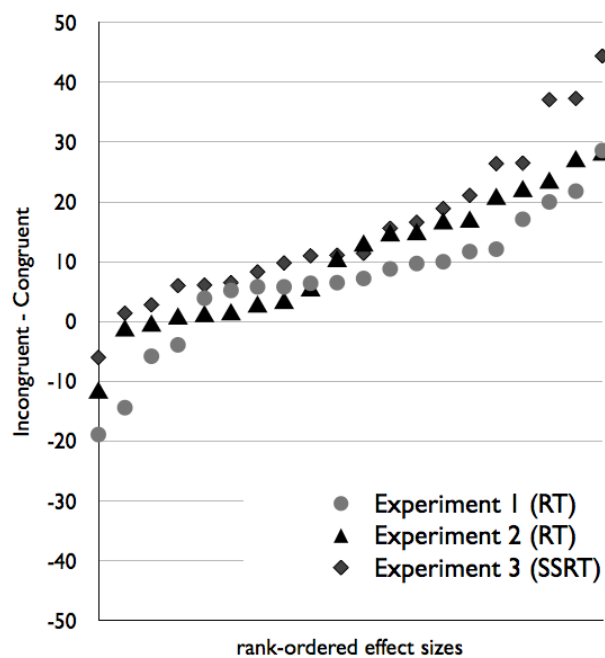
Figure 1

Figure 2

Figure 3

Legend within figure:

- nogo, GO (dotted)
- nogo, STOP (dotted)
- go-only, GO (dashed)
- go-only, STOP (dashed)
- stop, GO (straight)
- stop, STOP (straight)

X-axis: 200.00   325.00   450.00   575.00   700.00

Figure 4

Figure 5

.....	congruent prime
———	neutral prime
- - -	incongruent prime