You better stop! Binding "stop" tags to irrelevant stimulus features

Carina Giesen[a] & Klaus Rothermund[a]

[a] Department of Psychology, Friedrich-Schiller-Universität Jena, Jena, Germany
Accepted author version posted online: 13 Aug 2013.Published online: 16 Oct 2013.

PLEASE SCROLL DOWN FOR ARTICLE

Routledge
Taylor & Francis Group

You better stop! Binding "stop" tags to irrelevant stimulus features

Carina Giesen and Klaus Rothermund

Department of Psychology, Friedrich-Schiller-Universität Jena, Jena, Germany

We investigated whether the basic process of integrating stimuli (and their features) with simultaneously executed responses transfers to situations in which one does *not* respond to a stimulus. In three experiments, a stop-signal task was combined with a sequential priming paradigm to test whether irrelevant stimulus features become associated with a "stop" tag. Stopping a simple response during the prime trial delayed responding and facilitated stopping in the probe if the same irrelevant stimulus feature was repeated in the probe. These repetition priming effects were independent of the relation between the to-be-executed (or to-be-stopped) responses in the prime and probe, indicating that "stop" tags are global ("stop all responses!") rather than being response-related (e.g., "stop left response!").

Keywords: Stimulus–response binding; Event files; Episodic retrieval; Response suppression; Stop-signal task.

When the traffic light turns green, we walk; when we notice something falling down, we catch it; when we want to open a door, we push the handle. Most of the time, we are not even aware of performing these actions, and we do not have to be: because we have learnt to associate stimuli (or types of stimuli) with specific responses. Recent instance-based theories (e.g., Logan, 1988) propose that for our cognitive system the mere temporal coactivation of a perceived stimulus and a selected response is sufficient to integrate these elements into a transient episodic memory structure—that is, a stimulus–response (S–R) episode or *event file* (Hommel, 1998). Repeating an element of an event file will then automatically retrieve the entire S–R episode, including the associated response. Automatic response retrieval from memory allows for an efficient regulation of behaviour because it is much faster than deliberately generating a response (Logan, 1988).

However, not only can relevant (target) stimulus and response features become integrated into an S–R episode (e.g., Denkinger & Koutstaal, 2009; Hommel, 1998, 2004; Horner & Henson, 2009, 2011; Logan, 1988; Waszak, Hommel, & Allport, 2003, 2005), but also even (task-)irrelevant stimulus features or entire distractor stimuli that merely accompany the target are bound with responses (i.e., distractor–response bindings; Rothermund, Wentura, & De Houwer, 2005). Subsequently, the (re-)presentation of the prime

809

distractor[1] suffices to trigger response retrieval processes, irrespective of whether it repeats as the new target in trial $n + 1$ (as is common practice in the negative priming, NP, paradigm, e.g., Gibbons & Stahl, 2008; Mayr & Buchner, 2006; Mayr, Buchner, & Dentale, 2009; Rothermund et al., 2005) or as a distractor (Frings & Rothermund, 2011; Frings, Rothermund, & Wentura, 2007; Giesen, Frings, & Rothermund, 2012; Giesen & Rothermund, 2011; Moeller & Frings, 2011; Moeller, Rothermund, & Frings, 2012; Rothermund et al., 2005). These findings illustrate that binding processes are pervasive and apply to a broad scope of stimuli, responses, and modalities.

Integrating irrelevant information into event files can be seen as an adaptive default configuration of the cognitive system because it allows for redundancy gains and implicit learning: Irrelevant features of stimuli can often be assumed to be informative with regard to correct behaviour in natural settings because they correlate with relevant features due to their co-occurrence within certain objects. For example, a potential predator may be identified by the shape of its body, which elicits a flight response. The colour of the predator's fur then also becomes associated with the flight response, which further enhances the activation of the flight response during subsequent encounters with the predator due to some kind of redundancy gain or Garner effect (Garner & Felfoldy, 1970).

Automatically retrieving responses that were previously associated with a stimulus offers one possibility (among others) of efficient behaviour control, particularly if resources are scarce, and circumstances are demanding. Although such a resource-saving mode of behaviour regulation certainly has it merits, at times, *not* performing any

response is probably the most adaptive of all behaviours. Indeed, there are situations in which one is well advised either to purposefully hinder response execution or to try to stop a response that has already started: Would you catch a falling knife? Or a razor blade? We would assume rather not. In the depicted examples, responding in the habitual way (i.e., catching a falling object) turns out to be highly dysfunctional, and hence suppression of the response is in the interest of the person involved. However, stopping of a response, especially one that is otherwise highly likely to be executed, requires an extreme form of intervening cognitive control that overwrites the initial intention to respond with the antagonistic "stop" information (cf. Logan & Cowan, 1984). Such an abrupt change of response goals, however, should also affect binding processes. Against this background, it is interesting to note that research on binding mechanisms offers yet only little insight into the question of whether, and to what extent, nonresponse or stop information may also become part of a processing episode.

The aim of the present experiments is to fill this gap and to examine binding mechanisms for irrelevant stimulus features in situations in which the response is prevented rather than executed. Specifically, we hypothesize that if stopping an inappropriate response is successful, the presented stimulus and its features (even if they are task-irrelevant) should become associated—figuratively speaking, *tagged*—with the stop information. A subsequent stimulus repetition should then trigger retrieval of the *stimulus-stop* episode, including the stop association, which should interfere with the execution of a go response but should facilitate the suppression of a response (i.e., if yet another stop is required).

---

[1] In our usage, "distractor" is a broad concept that denotes all kind of (task-)irrelevant information that is presented in addition to task-relevant target stimuli (or features). Indeed, distractor–response binding effects have been documented for irrelevant features of a stimulus (i.e., a stimulus's identity in a categorization task, Rothermund et al., 2005) as well as for entire stimuli (i.e., letters/digits: Frings et al., 2007; Giesen et al., 2012; Rothermund et al., 2005; sounds: Mayr & Buchner, 2006; irrelevant words: Giesen & Rothermund, 2011) that occur simultaneously with target stimuli in selection situations. S–R bindings have been shown for distractors that compete with the target for a specification of the response (Giesen et al., 2012) as well as for distractors that are just irrelevant and are not associated with a specific response (Giesen & Rothermund, 2011). Importantly, automatic response retrieval effects closely correspond to each other irrespective of whether the distractor is an independent object on its own (Frings et al., 2007) or whether it is just an irrelevant feature of the target object (Rothermund et al., 2005).

The present idea of stimulus-stop episodes is reminiscent of Neill and colleagues' episodic retrieval account of NP (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). Neill et al. argued that if participants ignore a distractor in the prime, they encode it with a "do not respond" or "ignore it" tag. According to this account, repeating the prime distractor as the target in the following probe trial retrieves this tag, which interferes with the requirement to respond and thus delays responding (causing NP). The present account, however, goes beyond the predictions of Neill's episodic retrieval theory in proposing retrieval of stop tendencies even in those cases where the irrelevant prime stimulus is repeated as an irrelevant stimulus in the probe, which deviates from the standard NP paradigm. Furthermore, in NP studies, the response to the prime target is typically executed rather than withheld, which is why obtaining a NP effect under these conditions is more likely to reflect prime response retrieval (Mayr & Buchner, 2006; Mayr et al., 2009; Rothermund et al., 2005). To put the idea of stop information retrieval to a stringent test, we focused on situations in which response execution is prevented altogether in the presence of a prime stimulus.

Effects of response suppression on binding mechanisms can be studied with the *stop-signal paradigm* (e.g., Logan, 1994; Logan & Cowan, 1984). In this paradigm, participants have to perform a simple task in response to a stimulus for the majority of trials (the *go task*, e.g., "press left/ right key if the stimulus is an X/O"). However, on a randomly selected number of trials, a (typically auditory) stop signal is presented, which requires participants to withhold their response (*stop trials*). Importantly, the stop signal appears some variable time *after* onset of the go stimulus, which means that participants are often already preparing or executing the response when they first hear the signal. It is then of interest under which conditions participants are able to withhold their response and under which they are not. However, apart from offering a measure of stop performance (for a review, see Logan, 1994), the stop-signal task can also be employed as a means to examine after-effects

of previous successful stopping. Indeed, several studies reported increased response latencies if the target stimulus of a preceding stop trial was repeated in a subsequent go trial. These findings support the conclusion that the stop information was bound with the stimulus in trial $n − 1$ and was retrieved again in trial n, thereby interfering with performing the task-appropriate go response (e.g., Bissett & Logan, 2011; Rieger & Gauggel, 1999; Verbruggen & Logan, 2008a, 2008b; Verbruggen, Logan, Liefooghe, & Vandierendonck, 2008).

In sum, the evidence is consistent with the idea of a stimulus-induced retrieval of stop associations. However, in the above-mentioned studies, interference effects of previous stop trials were always tested on the basis of target stimulus repetitions. Delayed responding to a target stimulus that was previously presented in a stop trial might also indicate persistent inhibition of the link between the target and its associated response rather than being the result of a retrieval of the previous stimulus-stop episode (for a detailed discussion, see Pösse, Waszak, & Hommel, 2006; Verbruggen, Logan et al., 2008).

In order to investigate stimulus-stop bindings in a way that cannot be explained in terms of inhibition processes, we examined whether irrelevant stimulus features can also become integrated with a stop association and retrieve it upon later repetition, analogously to target stimuli. Showing that repetition of an irrelevant stimulus feature that was previously presented during a prime trial that required stopping a response interferes with responding in a go-trial probe (and facilitates stopping in a stop-trial probe) would provide more unambiguous evidence for the existence of stimulus-stop bindings, because such a finding cannot be explained in terms of an inhibition of stimulus–response associations.

Additionally, the employed sequential priming paradigm allows us to investigate another interesting question regarding the specificity of stimulus-stop bindings. Whereas previous studies revealed that stimulus–response bindings are specific—that is, they reflect an association between a stimulus and a particular response rather than between a stimulus and responding in general (e.g., Frings

et al., 2007; Hommel, 1998, 2004; Rothermund et al., 2005)—it is less clear whether stop information reflects a general tendency not to respond or whether it refers only to the specific response that has been stopped in the previous stop episode, preventing the reexecution of this particular response but not of other responses. Combining the repeated irrelevant feature with either the same or a different target feature in prime and probe allows us to investigate whether the previous stop trial interferes with subsequent go trials in general or whether it just hinders the execution of those responses that were suppressed during the previous stop trial. Such a flexible combination of the repeated stimulus with different responses is hard to achieve with a target repetition paradigm, because within each task, targets are linked to a specific response so that repeating the target feature implies a repetition of the response as well.

In this study, we conducted three experiments in which we employed a sequential priming paradigm: Two displays, referred to as *prime* and *probe*, appeared in close succession; in each prime and probe display, neutral adjectives were presented. Importantly, the identity of the words was always irrelevant for the to-be-performed task (i.e., word detection in Experiment 1, colour categorization in Experiments 2 and 3; Rothermund et al., 2005). Word identity either repeated from prime to probe (word repetition) or not (baseline condition). Because we aimed to assess whether the irrelevant identity of the word is integrated with stop associations (in the prime) and retrieves them later on (in the probe), we combined this sequential priming paradigm with a stop-signal task. That is, stop signals were presented on some randomly selected prime and/or probe trials (stop trials), while the remaining trials served as go trials.

This paradigm is ideally suited to investigate stimulus-based binding and retrieval effects, since it allows us to calculate repetition effects (computed as the difference of word repetition minus baseline probe trials), which function as a direct index of performance (dis)advantages due to feature-based retrieval processes, relative to the baseline condition. We can hence investigate how repetition of an irrelevant feature from previous prime stop

trials will affect go and stop performance in subsequent probe trials: Whenever a response is successfully stopped in a prime trial, repeating the irrelevant prime word in the probe provides a measure for feature-induced retrieval of the stop information: If a go response is required in the probe, a retrieved stop association is inappropriate and will interfere with response execution, which means we should observe impeded performance in probe go trials. In probe stop trials, however, the retrieved stop association matches the demands of the probe and should facilitate stopping in the probe as well, implying that we should observe fewer errors to commit a response in stop trial probes.

To further substantiate our reasoning, we also analysed prime trials in which participants failed to stop their response. These trials are of particular interest because they allow us to test for potential alternative explanations of the predicted effects. For instance, rather than reflecting a stimulus-stop binding, our findings might also be taken to reflect the association between the irrelevant word's identity and the stop signal itself (i.e., a stimulus–stimulus association). If this were the case, then we should obtain a similar pattern of findings irrespective of whether participants succeeded or failed to stop the response in a prime stop trial. However, we consider it more likely that unsuccessful prime stop trials will reflect a pattern of stimulus–response bindings, because participants failed to stop and instead executed the response in the prime. Accordingly, for prime stop trials in which participants failed to withhold their response and for prime go trials (i.e., trials without stop signal), repetition of the irrelevant prime word in the probe provides a measure of prime response retrieval (e.g., Frings et al., 2007; Rothermund et al., 2005). If the same response that was executed in the prime is also required in a subsequent probe go trial, prime response retrieval due to word repetition should facilitate response execution (faster performance). Repeating the prime word's identity in a stop trial probe, however, should interfere with the stopping requirement in the probe, resulting in more failures to stop this response in a stop trial probe.

EXPERIMENT 1

In Experiment 1, stimulus onset served as the task-relevant dimension: Participants were instructed to press the space bar whenever a word appeared on the screen for both prime and probe trials. The word's identity, however, was irrelevant for this detection task. In some (prime and/or probe) trials, an auditory stop signal appeared, which required participants to withhold their response. Word relation was manipulated, implying that words either repeated or changed from prime to probe (word repetition vs. baseline). Furthermore, we manipulated whether a stop signal was presented in prime and/or probe or not.

Method

Participants
Fifty-two students of the University Jena took part in the experiment. One participant did not follow instructions to respond fast (outlier with respect to the speed criterion according to Tukey, 1977; for details see below) and had to be excluded because of too few fast responses. One participant had empty cells with respect to the conditions of interest and had to be excluded as well. Thus, data of 50 (26 female) participants were analysed. All participants reported German as their native language. Participants' mean age was 23.9 years ($SD = 4.9$). They were tested individually and received 2 euros for their participation and a chocolate bar if their performance fulfilled criteria of both speed and accuracy. Experimental sessions lasted approximately 25 minutes.

Apparatus and stimuli
The experiment was programmed with E-Prime 2.0. An auditory sinusoidal tone (750 Hz, 75 ms, 75 dB) served as stop signal and was presented through closed headphones (TDK MP-100). Twenty-five neutral frequently used German adjectives served as stimuli in the experiment. All were either mono- or disyllabic and consisted of 4 to 7 letters (e.g., *small, quiet, edgy*). Stimuli were presented centrally in white font (Times New Roman with 16-pt font size) on a black screen of a 17-inch CRT monitor. Participants gave their response by pressing the space bar of a QWERTZ keyboard.

Design
The experiment comprised a $2 \times 2 \times 2$ within-subject design with the factors word relation, prime trial type, and probe trial type, which were manipulated orthogonally. Word relation was manipulated either by repeating the prime word in the probe (word repetition, 50% of all prime/probe sequences; e.g., small–small) or by presenting two different words in prime and probe (baseline, 50% of all prime/probe sequences; e.g., quiet–small). Secondly, prime trial type was varied by presenting a stop signal (prime stop trials, 25% of the prime trials), or not (prime go trials, 75% of the prime trials). Thirdly, probe trial type was manipulated in a similar manner by either presenting a stop signal (probe stop trials, 25% of the probe trials), or not (probe go trials, 75% of the probe trials). There were two dependent variables of interest—namely, reaction times (RTs) in probe go trials and erroneous execution of a response in probe stop trials.

Procedure
Instructions were given on the screen. In each trial, a word stimulus appeared centrally on the screen. For both prime and probe displays, participants' task was to press the space bar as soon as the word appeared (*go task*). The identity of the word was irrelevant for the task in prime and probe displays (Rothermund et al., 2005). A brief auditory tone was presented via headphones on some trials, in which the response had to be withheld (*stop task*). In order to reduce strategic slowdown of response latencies in the go task due to the introduction of a stop task (see Logan, 1994), participants were informed that the stop signal would sometimes occur early, allowing them to prevent their response most of the time, while at other times, the stop signal would occur rather late, making it impossible for them to stop. Participants were encouraged to try to stop if they could, but were strictly reminded not to wait for the stop signal and were instructed to try not to

be influenced by the stop task when performing the go task, during which they had to respond as fast as possible.

After the instructions, participants performed a practice block of 32 prime–probe sequences in which they received feedback for every erroneous reaction—that is, if participants executed a response after a stop signal, the message "*Stopsignal–nicht reagieren*" ("stop signal–do not respond") appeared for 1000 ms; if participants failed to execute a response in a go trial, the message "*Fehler–Leertaste drücken*" ("Error–press space") appeared for 1000 ms. The practice block was repeated if a participant failed to stop in more than two thirds of all stop trials or if median RT in the go trials exceeded 600 ms. After the practice block, participants were told that they would receive a chocolate bar as an extra reward if they performed the task quickly (faster than 600 ms in 75% of the go trials) and without making too many errors (less than 50% go responses during stop trials).

Participants then performed 320 experimental prime–probe sequences that were constructed with respect to the factorial design. For each sequence, a prime word was randomly chosen from the stimulus set. In case of identical repetition, the prime word was presented as the probe word, too, whereas for the baseline condition, different words were presented in prime and probe displays. Care was taken that the identical stimulus was never sampled for two successive prime–probe sequences.

The stop signal was initially presented 150 ms after word onset; subsequently, onset of the stop signal was continually adjusted with a tracking procedure (Logan, 1994). That is, whenever a participant successfully stopped a response after a stop signal, the next stop signal would occur 25 ms *later*, making it more difficult to stop. However, if a participant failed to stop a response or responded very fast before the stop signal occurred, the next stop signal would occur 25 ms *earlier*, making it easier to stop. We implemented an upper bound into the tracking procedure to prevent loss of valid stop signal trials due to very fast responses that were executed before a stop signal was presented. The stimulus onset asynchrony (SOA) between word and stop signal could not take

values higher than the RT that corresponded to the 25th percentile of the individual go trial RT distribution. Still, trials in which a fast response was registered before the onset of the stop signal comprised approximately 10% of prime and probe stop trials (for details, see Results section) in which a stop signal was scheduled to occur. For participants, these trials were indistinguishable from standard go trials, because the stop signal was not presented if the response had already been completed before the stop signal.

Each prime–probe sequence was as follows (see Figure 1a): First, a fixation marker (+) was presented centrally for 250 ms, followed by the prime display in which a word stimulus was shown. The stimulus remained on the screen until participants pressed the space bar or until a maximal duration of 1500 ms had elapsed. Then the fixation marker was again presented centrally for a variable duration (between 150 and 350 ms, $M = 250$ ms) to prevent an exact anticipation of the onset of the probe display. Subsequently the probe display appeared, in which another word stimulus was presented, which remained on the screen either until participants pressed the space bar or until 1500 ms had elapsed. After an intertrial interval of 1250 ms with a blank black screen, the next prime–probe sequence started.

Halfway through the experiment, participants were given a short break. At the end of the experiment, participants were asked whether they had used any strategies during the task. Finally, participants received feedback with regard to the speed and accuracy criteria and were thanked, debriefed, and rewarded accordingly.

Results

Analytical approach
RT in probe go trials and failures to stop a response in probe stop trials served as the two dependent variables of interest. Since we were interested in performance (dis)advantages in probe trials due to feature-based retrieval processes, we computed repetition effects from average probe go RTs and average probe stop error rates (see Table 1) by subtracting baseline trials from trials with word
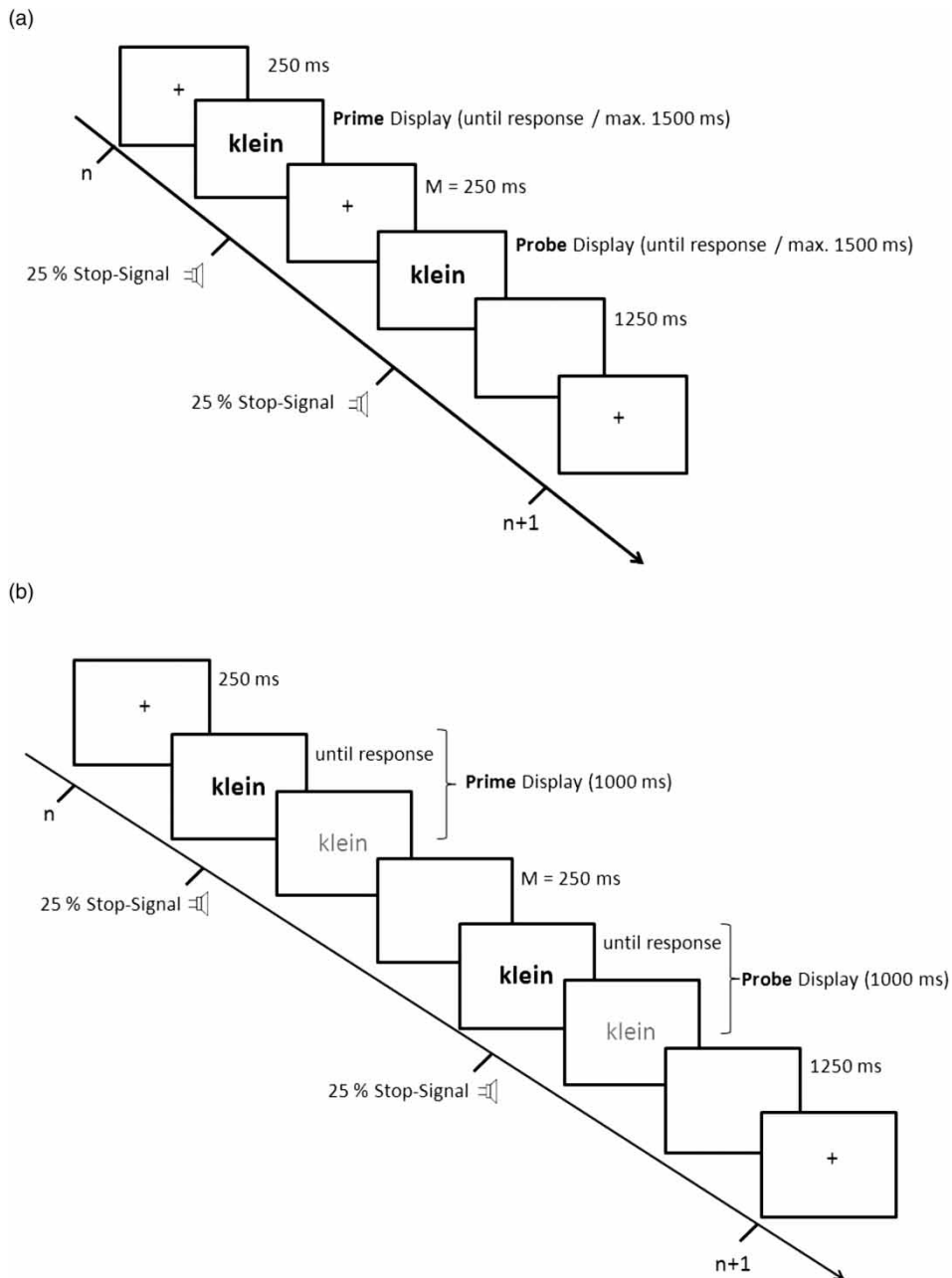
Figure 1. *Schematic display of the trial structure in (a) Experiments 1 and 2 and (b) Experiment 3. For each prime–probe sequence, participants reacted via key press to the word stimulus by performing a detection task (Experiment 1) or a colour categorization task (Experiments 2 and 3). Stimuli are not drawn to scale. In Experiment 3, stimuli were initially presented in red or green font (depicted in black and boldface) and "lost" their colour (depicted in gray) as soon as participants responded.*

Table 1. *Means of reaction times in probe go trials and error rates in probe stop trials in Experiments 1 to 3*

		RT (Probe go trials)						% Errors (Probe stop trials)		
	Condition	Stimulus relation						Stimulus relation		
Experiment	Prime trial type	Repetition		Baseline		$RE = \Delta_{repetition-baseline}$		Repetition	Baseline	$RE = \Delta_{repetition-baseline}$
Experiment 1	Successful stop	500 (136)		486 (135)		14 [8]		30.2 (24.4)	38.8 (28.3)	−8.6 [3.9]
	Go	450 (140)		461 (143)		−11 [3]		30.3 (13.6)	29.2 (14.3)	0.9 [1.8]
	Unsuccessful stop	636 (171)		665 (187)		−29 [16]		23.6 (30.2)	22.8 (30.1)	0.8 [5.5]
		Response relation								
		SR	DR	SR	DR	SR	DR			
Experiment 2	Successful stop	585 (97)	562 (92)	573 (99)	554 (89)	12 [9]	8 [7]	25.6 (22.3)	34.9 (23.3)	−9.3 [3.4]
	Go	465 (103)	535 (97)	485 (106)	528 (96)	−20 [4]	7 [3]	34.8 (15.1)	33.8 (14.5)	1.0 [2.0]
	Unsuccessful stop	646 (123)	651 (114)	670 (140)	623 (123)	−24 [14]	28 [14]	40.7 (32.3)	31.9 (32.6)	8.8 [5.4]
Experiment 3	Successful stop	618 (103)	594 (107)	611 (115)	589 (109)	7 [6]	5 [7]	28.8 (20.1)	30.4 (24.4)	−1.6 [4.1]
	Go	543 (114)	579 (92)	555 (113)	569 (96)	−12 [3]	10 [3]	32.9 (12.0)	32.7 (11.6)	0.2 [1.9]
	Unsuccessful stop	646 (125)	619 (124)	650 (138)	618 (133)	−4 [14]	1 [13]	25.7 (28.5)	34.0 (33.5)	−8.3 [5.8]

Note: RT = reaction time in ms. Standard deviations in parentheses. Standard error of the mean in squared brackets. RE = repetition effect, computed as the difference between repetition and baseline; SR = same response; DR = different response.

repetitions (word repetition minus baseline) for every condition of the prime trial type factor and separately for each participant. Repetition effects for probe go RT and probe stop error rates were then entered into separate analyses of variance (ANOVAs) with the within-subject factor prime trial type (go vs. successful stop vs. unsuccessful stop). To disentangle effects of stimulus-stop binding and stimulus-based retrieval of the executed prime response, we further decomposed effects of the prime trial type factor into two a priori contrasts —namely, "go versus successful stop trials" and "go versus unsuccessful stop trials". In the following, results of the overall ANOVA, contrast decomposition, and follow-up tests on significant contrasts are presented separately for probe go and probe stop trials.

Probe go trials

Fast responses during stop trials that occurred before the onset of the stop signal were treated as go trials (8.5% of all prime stop trials; 9.8% of all probe stop trials). With respect to the RT analyses, 1% of all probe go trials were excluded because participants failed to respond within 1500 ms in the present probe or preceding prime trial although no stop signal was presented. Also, probe go RTs that were below 100 ms or more than 3 interquartile ranges above the third quartile of the individual RT distribution were treated as outliers (3.6%; Tukey, 1977) and were discarded from analyses.

Mean probability of successful stopping was .65 ($SD = .14$) in prime stop trials and .71 ($SD = .12$) in probe stop trials[2]; mean prime stop signal delay was 273 ms ($SD = 116$ ms), and mean probe stop signal delay was 273 ms ($SD = 112$ ms).

The one-way ANOVA on probe go RT showed that the main effect of prime trial type on repetition effects was significant, $F(2, 48) = 5.55$, $p = .007$, $\eta_p^2 = .19$. Planned contrasts indicated that the repetition effects differed in the predicted way with respect to the "go versus successful stop" contrast,

$F(1, 49) = 7.99$, $p = .007$, $\eta_p^2 = .14$. Follow-up tests indicated that after prime go trials, participants responded significantly faster if the prime word's identity was repeated in the probe than in the baseline condition [$\Delta_{repetition-baseline} = -11$ ms, $t(49) = -3.56$, $p = .001$] replicating typical stimulus–response binding and retrieval effects (Rothermund et al., 2005). However, and most importantly, after successful prime stop trials, participants' response time was significantly delayed if the prime word's identity was repeated in the probe [$\Delta_{repetition-baseline} = 14$ ms, $t(49) = 1.75$, $p = .04$, one-tailed]. The results are in line with our assumption that the irrelevant prime feature becomes associated with a "stop" tag in a successful prime stop trial that, once retrieved, interferes with the response that is required in a go trial probe. In contrast, repetition effects with respect to the "go versus unsuccessful stop" contrast did not differ, $F(1, 49) = 1.45$, $p > .23$. After unsuccessful prime stop trials, the pattern of results closely mimicked the pattern of prime go trials, reflecting effects of stimulus–response binding and retrieval (see also Figure 2a): Responding in the probe was facilitated after go and unsuccessful stop trials if the word's identity was repeated compared to the baseline condition [$\Delta_{repetition-baseline} = -29$ ms, $t(49) = -1.87$, $p = .03$, one-tailed].

Probe stop trials

Overall, 0.06% of probe stop trials were excluded due to nonexecution of the go task in the prime.[3]

The one-way ANOVA on probe stop error rates showed that the main effect of prime trial type approached significance, $F(2, 45) = 2.79$, $p = .07$, $\eta_p^2 = .11$. We again decomposed this effect in two planned contrasts. As expected, repetition effects differed in the predicted way with respect to the "go versus successful stop" contrast, $F(1, 46) = 5.52$, $p = .02$, $\eta_p^2 = .11$: Follow-up analyses showed that after prime go trials, error rates in probe stop trials did not differ for the word repetition and baseline

---

[2] Introducing an upper limit for stop signal delays to reduce fast responses that occur before stop signal onset implied a reduction of the amount of late (i.e., difficult) stop signals. Hence, the mean probabilities of stopping obtained in the present experiments positively exceed .50, which one would normally expect with a balanced tracking procedure.

[3] For three participants of Experiment 1, three participants of Experiment 2, and five participants of Experiment 3, the restrictions of the factorial design led to empty cells with respect to the conditions of interest, hence only $n = 47$ (Experiment 1), $n = 52$ (Experiment 2), and $n = 53$ (Experiment 3) participants entered into the analyses for probe stop trials.

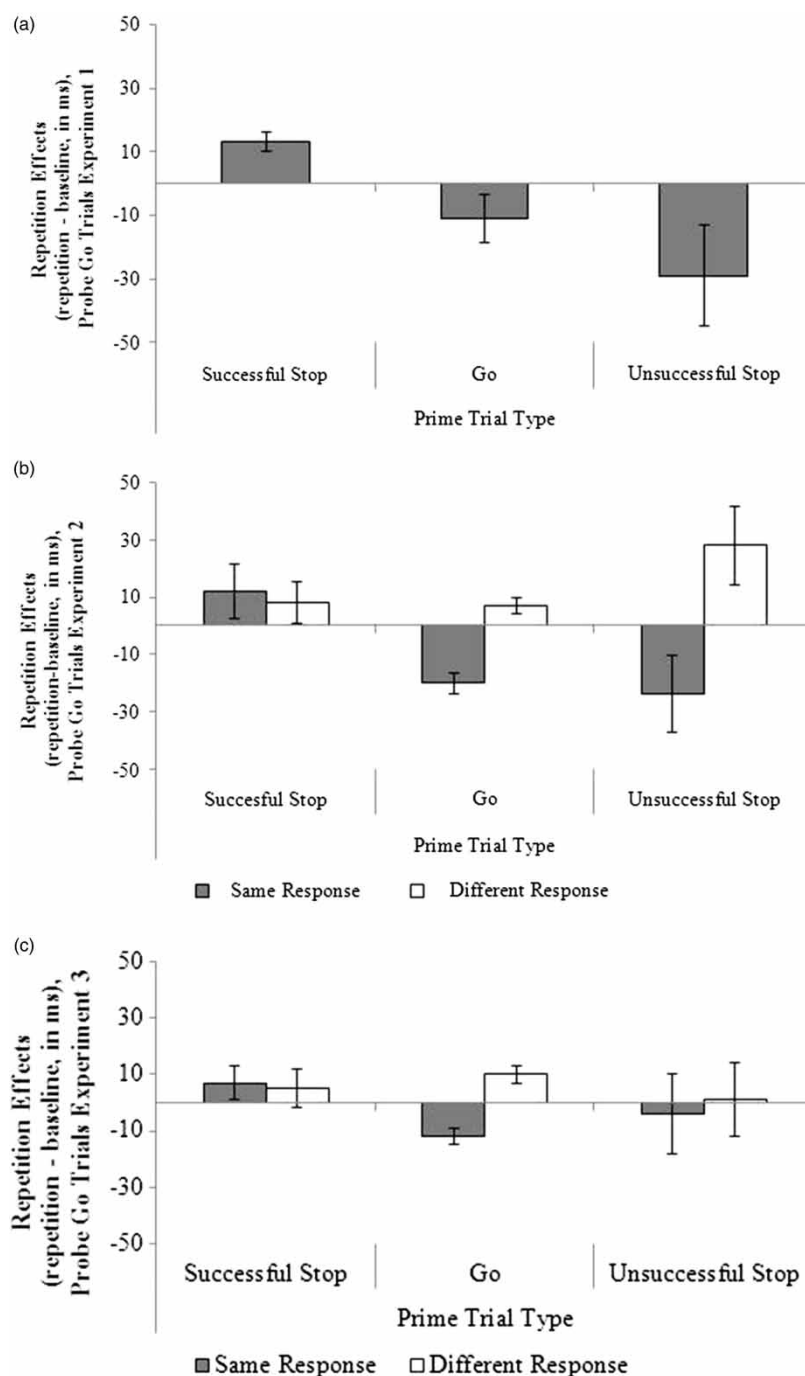Figure 2. Repetition effects (repetition − baseline) for probe go trial reaction times (in ms) as a function of (a) prime trial type (Experiment 1) and (b, c) prime trial type and response relation (Experiments 2 and 3). Error bars depict the standard errors of the means. For probe go trials, negative (positive) values indicate facilitated (delayed) probe performance due to repetition of the word's identity compared to baseline.

conditions ($\Delta_{\text{repetition}-\text{baseline}} = 0.9\%$, $|t| < 1$). However, after successfully stopping in the prime, participants made fewer stop errors if the prime word's identity was repeated in the probe [$\Delta_{\text{repetition}-\text{baseline}} = -8.6\%$, $t(46) = -2.18$, $p = .03$ (see Figure 3a)]. In turn, repetition effects did not differ with respect to the "go versus unsuccessful stop" contrast, $F < 1$. Effectively, word repetitions in the unsuccessful stop condition had no influence on stop performance in the probe ($\Delta_{\text{repetition}-\text{baseline}} = 0.9\%$, $|t| < 1$). These findings correspond with our reasoning: If the irrelevant word identity was associated with a "stop" tag in a successful prime stop trial, its retrieval in a probe stop trial facilitated withholding the response again, leading to fewer stop trial errors; no such influence of word repetitions on stop performance was obtained after go and unsuccessful stop trials, in which a response was executed in the prime.

Discussion

There are two striking observations with respect to the obtained results. First, repeating the irrelevant identity of a stimulus after a prime go trial led to faster responses in probe go trials, reflecting distractor–response binding and retrieval effects (e.g., Frings et al., 2007; Rothermund et al., 2005). Second, Experiment 1 aimed to test whether the irrelevant stimulus identity is associated with stop information if the prime trial requires participants to withhold the response and whether subsequent repetition of the word's identity in the probe retrieves this information. Evidence for such a stimulus-stop binding obtained in two analyses: Repeating the word's identity in the probe trial when the prime response had been successfully withheld delayed responding in probe go trials and reduced the frequency of failures to stop a response in probe stop trials. These results indicate that the irrelevant stimulus feature retrieved the stop information from the prime trial, which interfered with performing the appropriate response in probe go trials and facilitated the required suppression of a response in probe stop trials. Importantly, this pattern of findings indicating retrieval of stop information was restricted to those prime–probe

sequences in which the prime response was successfully stopped, and it did not prevail in those sequences in which the prime response was executed despite a stop signal. In the latter case, the findings paralleled the standard result of distractor–response binding and retrieval that was also found for prime go trials. This pattern of findings substantiates our claim that the irrelevant stimulus features became associated with some kind of a behavioural stop tendency (stimulus-stop association), and it speaks against an alternative account of our findings according to which the word's identity became associated with and later retrieved the stop signal (stimulus–stimulus association). Hence, the present results provide first evidence that irrelevant features become associated with a tendency not to respond during successful stop trials.

Although the detection task used in Experiment 1 allowed for a straightforward test of stimulus-stop binding and retrieval effects, it does not provide any information regarding the response-specificity of these "stop" tags. Is the "stop" information related to the response that has been stopped during the prime, preventing the reexecution of this particular response—but not others—if the prime word's identity is repeated? Or does the "stop" tag convey a general tendency not to respond if this stimulus is reencountered again in the future, regardless of whether the previously stopped response matches the response that is required on the second encounter?

Because there is only one possible response in the detection task, making it impossible to manipulate the response relation between prime and probe, findings of Experiment 1 do not allow us to distinguish between these two possibilities. Hence, we conducted another experiment in which we changed the single-response detection task into a binary colour classification task that allowed us to analyse effects of word repetitions after a prime stop trial separately for prime–probe sequences with specific response repetitions and response alternations, respectively.

The aim of Experiment 2 was to investigate whether stop tags are response-specific (e.g., "stop left response!") leaving other responses unaffected, or whether stop tags contain global, response-unspecific information (e.g., "stop all responses!"). If the former holds true, repeating the word after

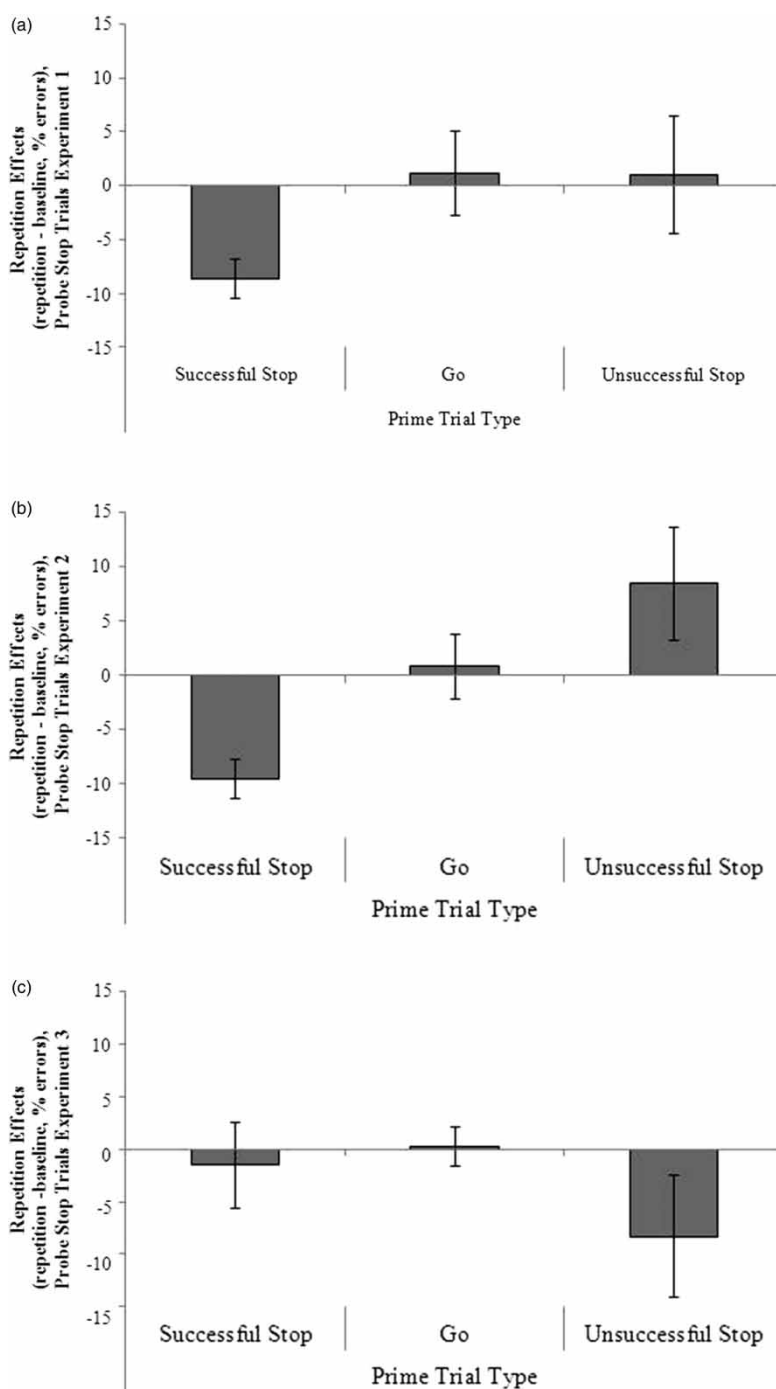**Figure 3**. *Repetition effects (repetition − baseline) for errors in probe stop trials as a function of prime trial type in (a) Experiment 1, (b) Experiment 2, and (c) Experiment 3. Error bars depict the stand errors of the means. For probe stop trials, negative (positive) values indicate fewer (more) failures to stop a probe response due to repetition of the word's identity compared to baseline.*

a prime stop trial should lead to a selective performance deficit in probe go trials only for sequences with response repetition (i.e., same colour in prime and probe). If the latter holds true, word repetitions after prime stop trials should interfere with responding in go trial probes for response repetition and response change sequences alike.

EXPERIMENT 2

Method

Participants

Sixty-nine students of the University Jena took part in the experiment. Nine participants had to be excluded because of too few fast responses (all were outliers with respect to the speed criterion; Tukey, 1977); another five participants had empty cells with respect to the conditions of interest and had to be excluded as well. Thus, data of 55 (33 female) participants were analysed. All participants reported German as their native language. Participants' mean age was 22.8 years (SD = 3.5). Duration and payment paralleled those in Experiment 1.

Materials, design, and procedure

Materials, design, and procedure were identical to those in Experiment 1 except for the following changes: We changed the go task to a colour categorization task. Therefore, word stimuli were presented in either red or green font colour. Participants had to press "D" if the stimulus was presented in red and "L" if the stimulus was shown in green for both prime and probe displays.

The binary colour categorization task allowed us to introduce response relation as another within-subject factor to our design, which was manipulated either by presenting the words in the same colour in prime and probe (same response; e.g., green–green) or by changing the required response from prime to probe (different response; e.g., green–red).

Because the categorization task was more demanding than the detection task, participants performed a practice block of 64 prime–probe sequences first. The feedback for errors in the go task was changed to "*Fehler–falsche Taste*" ("Error–wrong key"). The practice block was repeated if participants failed to stop in more than two thirds of all stop trials or made errors in more than one third of all go trials or if their median RT in go trials exceeded 1000 ms.

After finishing the practice block, participants were informed that they would receive a chocolate bar as an extra reward if they responded faster than 1000 ms in 75% of all go trials and did not erroneously respond after a stop signal in more than 50% of all stop trials, respectively.

Participants then performed 320 experimental prime–probe sequences that were constructed with respect to the experimental factors and the same constraints (e.g., timing of prime and probe displays; upper bound to the tracking procedure) as in Experiment 1. Response relation was varied orthogonally to the other factors, with half of the prime/probe sequences requiring the same response (SR) trials, and the other half requiring different responses (DR) in prime and probe.

Results

Analytical approach

Computation of repetition effects and contrast decomposition of the prime trial type factor paralleled those in Experiment 1. For probe go RT, response relation across prime and probe was considered as an additional factor, so that repetition effects were entered into a 3 × 2 ANOVA with the within-subject factors prime trial type (go vs. successful stop vs. unsuccessful stop) and response relation (same vs. different response). However, for probe stop error rates, data were collapsed across the levels of the response relation factor to enhance power for the contrasts of interest,[4] meaning that we performed

---

[4] Restricting the analysis to only those probe stop trials in which the "correct" response was erroneously executed after the stop signal and introducing response relation as an additional factor in the ANOVA led to a large amount of missing cells in the data matrix and would have led to a loss of more than 53% of participants (Experiment 2) and more than 44% of participants (Experiment 3) for this analysis. We thus decided to drop the response relation factor from this analysis and to collapse across the two conditions.

the same one-way ANOVA on probe stop error rates as that in Experiment 1 (see Table 1).

Probe go trials

Stop trials with fast responses that were committed before stop signal onset were treated as go trials (7.4% of all prime stop trials; 12.6% of all probe stop trials). RTs of probe go trials were excluded if an erroneous response was given in a prime and/or probe go trial (4.5% of probe go trials). RT outliers in probe go trials were also discarded from analyses (0.9%).

Mean probability of successful stopping was .67 ($SD = .09$) in prime stop trials and .67 ($SD = .12$) in probe stop trials; mean prime stop signal delay was 353 ms ($SD = 79$ ms), and mean probe stop signal delay was 353 ms ($SD = 81$ ms).

The 3×2 ANOVA on probe go RT revealed a significant main effect of response relation, $F(1, 54) = 11.97$, $p = .001$, $\eta_p^2 = .18$. Compared to the baseline, word repetitions in the probe led to faster performance if the same response had to be executed in prime and probe, but delayed performance if different responses were required in prime and probe. Furthermore, the main effect of prime trial type was significant, $F(2, 53) = 3.56$, $p = .03$, $\eta_p^2 = .12$. Planned contrasts with respect to the different factor levels of prime trial type revealed that repetition effects differed only with respect to the "go versus successful stop" contrast, $F(1, 54) = 6.95$, $p = .01$, $\eta_p^2 = .11$, but not with respect to the "go versus unsuccessful stop" contrast, which was not significant ($F < 1$). Follow-up tests on the first contrast showed that repetition of the word's identity in the probe compared to the baseline led to faster performance after prime go trials [$\Delta_{\text{repetition}-\text{baseline}} = -6$ ms, $t(55) = -3.21$, $p = .002$], but delayed responding after successful prime stop trials [$\Delta_{\text{repetition}-\text{baseline}} = 10$ ms, $t(55) = 1.69$, $p = .04$, one-tailed].

Most central to our prediction, these main effects were further qualified by a significant interaction of Prime Trial Type × Response Relation, $F(2, 53) = 3.78$, $p = .02$, $\eta_p^2 = .13$. Planned contrasts revealed that this interaction was due to the "go versus successful stop" contrast, $F(1, 54) = 5.36$, $p = .02$, $\eta_p^2 = .09$: Follow-up tests on

the first contrast showed that for probe go trials preceded by a prime go trial, repetition effects differed significantly for each level of the response relation factor, $t(54) = -5.31$, $p < .001$ (see Figure 2b), replicating the well-known specific response retrieval effect triggered by a repetition of the prime word (e.g., Frings et al., 2007; Rothermund et al., 2005). Repeating the prime word's identity in the probe facilitated performance in sequences with the same response in prime and probe [$\Delta_{\text{repetition}-\text{baseline}} = -20$ ms, $t(54) = -5.36$, $p < .001$], due to retrieval of the appropriate response, but significantly delayed response latencies in sequences with different responses [$\Delta_{\text{repetition}-\text{baseline}} = 7$ ms, $t(54) = 2.64$, $p = .01$], because the retrieved prime response is now inappropriate and leads to response conflict in the probe. However, for probe go trials that followed a successful prime stop trial, we found no evidence for a response-specific performance deficit, since repetition effects were not significantly different for sequences with response repetition or change, $|t| < 1$. In turn, the "go versus unsuccessful stop" contrast did not contribute to the Prime Trial Type × Response Relation interaction, $F(1, 54) = 1.80$, $p > .18$: For probe go trials that followed an unsuccessful prime stop trial, repetition effects again differed significantly for each level of the response relation factor, $t(54) = -2.92$, $p = .005$, indicating that the prime word's identity was bound with and retrieved the prime response that had been executed in the prime (see Figure 2b). Repeating the prime word in the probe facilitated performance in sequences with the same response [$\Delta_{\text{repetition}-\text{baseline}} = -24$ ms, $t(54) = -1.78$, $p = .04$, one-tailed], but significantly delayed response latencies in sequences with different responses [$\Delta_{\text{repetition}-\text{baseline}} = 28$ ms, $t(54) = 2.05$, $p = .02$, one-tailed]. Taken together, the planned contrast indicated a similar pattern of results for the influence of response relation on repetition effects whenever a response was executed during the prime (go trials and unsuccessful stop trials) and a different pattern of findings for the influence of response relation on repetition effects for prime trials without responses (successful stop trials).

Probe stop trials

A total of 3.2% of all probe stop trials were excluded due to errors in the prime go task. Participants responded in spite of a stop signal with false colour responses in 0.4% of all probe stop trials, which were excluded from analyses (i.e., these failures to stop were not counted as regular errors because in addition to not stopping, the wrong response was executed); hence errors in probe stop trials reflect failures to withhold an otherwise correct colour response (see also Footnote 3).

The one-way ANOVA on probe stop error rates yielded a significant main effect of prime trial type, $F(2, 50) = 4.86$, $p = .01$, $\eta_p^2 = .16$. Planned contrasts again revealed that repetition effects differed with respect to the first "go versus successful stop" contrast, $F(1, 51) = 6.46$, $p = .01$, $\eta_p^2 = .11$ (see also Figure 3b): Follow-up tests indicated that after prime go trials, participants made slightly, yet nonsignificantly, more erroneous responses in probe stop trials if the word's identity was repeated ($\Delta_{\text{repetition}-\text{baseline}} = 0.93\%$; $|t| < 1$). In contrast, after successfully stopping their response in the prime, participants made fewer stop errors if the prime word was repeated in the probe [$\Delta_{\text{repetition}-\text{baseline}} = -9.3\%$, $t(51) = -2.73$, $p = .009$], which replicates the pattern of results obtained in Experiment 1. In turn, the "go versus unsuccessful stop" contrast yielded no significant results, $F(1, 51) = 1.7$, $p = .19$. Like in the prime go trial condition, word repetitions increased stop error rates in the probe after unsuccessful prime stop trials [$\Delta_{\text{repetition}-\text{baseline}} = 8.8\%$; $t(52) = 1.63$, $p = .06$, one-tailed]. Together, these analyses indicate a similar pattern of retrieval effects for those trials in which a response had been executed in the prime (go trials and unsuccessful stop trials) and a different pattern of repetition effects for the sequences in which responding had been inhibited in the prime (successful stop trials).

Discussion

Experiment 2 replicated the effects of repetitions of irrelevant stimulus features on probe performance following a prime stop trial. Specifically, repeating the word's identity in the probe trial when the prime response had been successfully withheld delayed responding in probe go trials and facilitated stopping in probe stop trials, indicating that irrelevant stimulus features were associated with the tendency to stop responding during the prime. Importantly, these effects were not qualified by the nature of the response that was stopped or that had to be executed in prime and probe. Regardless of whether the same or a different response from the one that had been stopped during the prime had to be executed (or stopped) in the probe, repetitions of the irrelevant stimulus features had the same delaying (or facilitating) effect on probe performance.

However, Experiments 1 and 2 have one shortcoming—namely, prime stimulus presentation times differed systematically between the different levels of the prime trial type factor.[5] On successful prime stop trials, stimuli remained on screen until 1500 ms elapsed, whereas in unsuccessful stop or go trials in the prime, stimuli disappeared as soon as participants responded. Hence, we cannot exclude that the differences in repetition effects that we found for the successful prime stop trials were due to the prolonged stimulus exposure rather than to the fact that the prime response had been stopped. In our view, an explanation of the previous findings in terms of differences in exposure duration is somewhat unlikely: Differences in exposure duration might explain why repetition effects might differ in strength (e.g., due to better learning or memory), but it is hard to explain the pattern of qualitative differences in repetition effects that obtained in the previous experiments merely on the basis of different time parameters. To overcome this problem, however, we conducted another experiment in which this confound was eliminated.

EXPERIMENT 3

Experiment 3 was an exact replication of Experiment 2, with the only difference that stimulus exposure

---

[5] We thank an anonymous reviewer for drawing our attention to this confound.

times in prime and probe displays were now held constant across go and stop trials. Initially, word stimuli were presented in either red or green font colour in prime and probe displays. In contrast to the previous experiments, word stimuli always remained on the screen for a fixed duration in order to allow for identical exposure to the irrelevant words across prime stop and go trials. However, if participants responded (on go trials or unsuccessful stop trials), word stimuli immediately "lost" their colour (i.e., the response-defining target feature) and were presented in white until the end of the trial. This change in colour was introduced to provide participants with a feedback that their response had been registered by the computer.

Method

Participants

Sixty-seven students of the University Jena took part in the experiment. Two participants had to be excluded because of too few fast responses (i.e., outliers with respect to the speed criterion); another seven participants had empty cells with respect to the conditions of interest and had to be excluded as well. Thus, data of 58 (35 female) participants were analysed. All participants reported German as their native language. Participants' mean age was 23.4 years ($SD = 4.8$). The experiment lasted approximately 30 minutes; participants received 2.50 euros for their participation and a chocolate bar if their performance fulfilled the speed and accuracy criteria (see Experiment 1).

Materials, design, and procedure

Materials, design, and procedure were identical to those in Experiment 2 except for the following changes: The duration of prime and probe displays was shortened to 1000 ms altogether to keep the overall duration of the experiment within reasonable limits. Participants again responded to each stimulus's colour in prime and probe displays (go task) but had to stop their response if a stop signal occurred (stop task). Hence, prime and probe stimuli were initially presented in red or green font colour. If participants responded, word stimuli changed their colour to white but remained

on screen, whereas if participants managed to stop their response, stimuli retained their initial colour until the prime and/or probe duration had elapsed (see Figure 1b).

Participants again started with a practice block of 64 prime–probe sequences which was repeated if participants failed to stop on more than two thirds of all stop trials or made errors in more than one third of all go trials or if their median RT in go trials exceeded 750 ms. As soon as participants finished the practice block, they were informed that they could gain a chocolate bar as extra reward if they responded faster than 750 ms in 75% of all go trials and did not erroneously respond after a stop signal in more than 50% of all stop trials, respectively. Participants then performed 320 experimental prime–probe sequences that corresponded to the experimental design and had the same constraints as those in Experiment 2.

Results

Analytical approach

Computation of repetition effects, contrast decomposition of the prime trial type factor, and the different ANOVAs performed on probe go RT and probe stop error rates paralleled those in Experiment 2 (see Table 1).

Probe go trials

Stop trials with fast responses that were committed before stop signal onset were treated as go trials (11.7% of all prime stop trials; 11.2% of all probe stop trials). RTs of probe go trials were excluded if an erroneous response was given in a prime and/or probe go trial (6.8% of probe go trials). RT outliers in probe go trials were also discarded from analyses (0.3%).

Mean probability of successful stopping was .68 ($SD = .08$) in prime stop trials and .69 ($SD = .08$) in probe stop trials; mean prime stop signal delay was 392 ms ($SD = 94$ ms), and mean probe stop signal delay was 394 ms ($SD = 96$ ms).

The 3×2 ANOVA on probe go RT indicated that neither the main effect of response relation nor the main effect of prime trial type was significant (all Fs < 1.3, all ps $> .25$). The interaction

of Prime Trial Type × Response Relation was marginally significant, $F(2, 56) = 2.69$, $p = .07$, $\eta_p^2 = .09$. Planned contrasts revealed that this interaction was due to the "go versus successful stop" contrast, $F(1, 57) = 4.95$, $p = .03$, $\eta_p^2 = .08$: Follow-up tests on this first contrast showed that for probe go trials preceded by a prime go trial, repetition effects differed significantly for each level of the response relation factor, $t(57) = -4.70$, $p < .001$ (see Figure 2c), indicating retrieval of the prime response. Repeating the prime word's identity in the probe facilitated performance in sequences with same responses in prime and probe [$\Delta_{\text{repetition}-\text{baseline}} = -12$ ms, $t(57) = -3.53$, $p = .001$] due to retrieval of the appropriate response, but significantly delayed response latencies in sequences with different responses [$\Delta_{\text{repetition}-\text{baseline}} = 10$ ms, $t(57) = 3.41$, $p = .001$], because the retrieved prime response is now inappropriate and leads to response conflict in the probe. However, for probe go trials that followed a successful prime stop trial, we found no evidence for a response-specific performance deficit, since repetition effects were not significantly different for sequences with response repetition or change, $|t| < 1$. In turn, the Prime Trial Type × Response Relation interaction was not due to the "go versus unsuccessful stop" contrast, which was not significant, $F < 1$, indicating that the pattern of repetition effects in the unsuccessful stop condition matched the pattern of results after prime go trials. Although the pattern of repetition effects for probe go trials that followed an unsuccessful prime stop trial matched that in the prime go trial condition, effects after unsuccessful prime stop trials were only weak and nonsignificant (RT advantage in response repetition sequences: $\Delta_{\text{repetition}-\text{baseline}} = -4$ ms, $|t| < 1$; RT disadvantage in response change sequences: $\Delta_{\text{repetition}-\text{baseline}} = 1$ ms, $|t| < 1$).

Probe stop trials

A total of 4.1% of all probe stop trials were excluded due to errors in the prime go task. Probe stop trials in which participants responded despite the stop signal with a false colour response (0.8%) were also excluded from analyses (see also Footnote 3).

The one-way ANOVA on error rates on probe stop trials showed that repetition effects did not differ significantly with respect to the different levels of the prime trial type factor, $F < 1$ (see Figure 3c).

Discussion

The results of Experiment 3 correspond well with the findings of both previous experiments, in particular with respect to the critical conditions of interest—namely, the effect of successful prime stop trials as compared to prime go trials on word repetition in the subsequent probe trial. Whereas repetition of the same word in the probe after a prime go trial yielded a pattern indicative of stimulus-based retrieval of the executed prime response, successful stopping of a response in the presence of a prime word delayed subsequent probe performance if the same word was repeated. Furthermore, this general repetition cost prevailed regardless of whether responses were the same or different between prime stop and probe go trials, suggesting that the word's identity retrieved a global, response-unspecific "stop" association.

Most importantly for the present purposes, since stimulus presentation in the prime was of equal duration (i.e., 1000 ms) for all conditions of the prime trial type factor, we can positively refute the possibility that the observed differences in the pattern of word repetition effects between these conditions are related to exposure time. By implication, these findings also support the conclusion that the findings that were obtained in Experiments 1 and 2 reflect genuine differences between stop and go episodes.

Admittedly, the pattern of effects was somewhat less pronounced in Experiment 3 than in the previous experiment. A close match in the pattern of repetition effects was obtained for the prime go and successful stop conditions. For the unsuccessful stop condition, however, the previous pattern of effects could not be replicated. In our view, there is an obvious explanation for this lack of systematic and significant retrieval effects in this specific

condition: Longer presentation times after an erroneous response in a stop trial allow for extensive reflection and induce all kinds of cognitive control operations. This kind of error-related processing is aimed at neutralizing the influence of the previous faulty S–R episode on future responding, which should also lead to an elimination of retrieval effects relating to this event (Colzato, van Wouwe, & Hommel, 2007; Rothermund, Eder, & Frings, 2013; Waszak & Pholulamdeth, 2009). Importantly, the identical prolongation of presentation times had no effect on the pattern of retrieval effects for the standard prime go trials. This finding allows us to conclude that the elimination of retrieval effects in the unsuccessful stop condition is error-specific and cannot be attributed to the extension of presentation times per se. Due to the fact that the pattern of retrieval effects in the standard go condition was unaffected by the variation of stimulus presentation times and still differed qualitatively and significantly from the successful stop condition, we can refute alternative explanations of our findings in terms of differences in presentation times.

Another point has to be discussed regarding the validity of the findings suggesting a nonspecificity of stimulus-stop bindings in Experiments 2 and 3: One might argue that the conclusion of nonspecific stimulus-stop bindings rests on null findings (nonsignificant influence of response relation on repetition effects after prime stop trials), and should thus be interpreted with caution. Several aspects of our study, however, speak in favour of the validity of our interpretation of the data. First, due to the fairly large sample size, the power of the studies to detect effects was substantial in both experiments (e.g., the probability to detect a medium sized effect was $1 - \beta > .97$).[6] Second, significant repetition effects obtained even within the "different response" conditions of our study, indicating the retrieval and application of stop information from the prime although the probe was linked to a different response than the prime. Finally, the significant interaction of response relation and prime trial type provides positive

evidence for the qualitative difference of stimulus–response bindings and stimulus-stop bindings. Whereas effects of stimulus–response bindings (resulting from prime go trials and unsuccessful prime stop trials) depended on the relation between prime and probe responses, indicating the standard response-specific binding and retrieval of irrelevant stimulus features and responses that had been obtained in previous studies (e.g., Frings et al., 2007; Rothermund et al., 2005), this was clearly not the case for stimulus-stop bindings (resulting from trial sequences in which the prime response had been successfully stopped).

GENERAL DISCUSSION

In the last few years, evidence for the integration of irrelevant stimuli (or features) into S–R episodes has accumulated, documenting that distractor repetition triggers retrieval of central elements of these episodes (Boronat & Logan, 1997; Frings & Rothermund, 2011; Frings et al., 2007; Gibbons & Stahl, 2008; Giesen et al., 2012; Giesen & Rothermund, 2011; Logan & Etherton, 1994; Mayr & Buchner, 2006; Mayr et al., 2009; Moeller & Frings, 2011; Moeller et al., 2012; Rothermund et al., 2005). In the present study, we subjected distractor integration effects to a further test and investigated whether irrelevant stimulus features can also be associated with the explicit goal *not* to respond. In order to examine retrieval of such stop associations, we combined a sequential priming paradigm (Rothermund et al., 2005) with a stop-signal task (Logan, 1994). The results of three experiments substantiate our reasoning that stop goals are bound to irrelevant stimulus features and are automatically retrieved from memory once these features are repeated. Specifically, repetition of a word's identity that became associated with stopping in the prime led to slower reaction times in probe go trials, but also evoked fewer failures to stop a response in probe stop trials. These results correspond with previous studies that demonstrated stimulus-

---

[6] Post hoc power analyses were conducted with G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007).

induced retrieval of stop associations (Verbruggen & Logan, 2008a, 2008b; see also Bissett & Logan, 2011; Rieger & Gauggel, 1999; Verbruggen, Logan et al., 2008). However, these previous studies exclusively relied on repeating the target stimulus of preceding stop trials, and one cannot exclude that alternative processes might underlie the obtained results. For instance, successful response inhibition in a previous trial might weaken the link between the target stimulus and its assigned response (Pösse et al., 2006; Verbruggen, Logan et al., 2008). If the target is repeated in a subsequent go trial, the response is not as easily accessible so that response execution will take longer. The present experiments exclude this alternative explanation, because they focused on associations between stop information and irrelevant stimulus features, instead of a target stimulus. Stimulus identity was not relevant for the to-be-performed task and was not assigned to any response, which implies that there is no stimulus–response connection to be weakened. Hence, we take the present findings as evidence that irrelevant stimulus features were associated with the goal not to respond in prime stop trials, which was stored as a stimulus-stop association in memory. Our findings thus complement existing research on distractor–response bindings and stimulus-stop associations in demonstrating that memory retrieval of stop associations can also be triggered by irrelevant stimulus features.

Retrieval of stop tendencies or stop signals?

By comparing the effects of successful and failed attempts to stop responding in the prime to the effects of prime go trials, the current study allows us to pit an explanation of our findings in terms of stimulus-stop bindings against an alternative account in terms of associations between the irrelevant feature and the stop signal (stimulus–stimulus binding). Results show that a retrieval of stopping tendencies occurs only in a situation in which the prime response was effectively withheld. The mere presence of the stop signal in the prime without successful stopping does not lead to a retrieval of stopping tendencies in the probe;

instead, in this case the pattern of retrieval effects parallels the standard pattern of S–R retrieval that is also obtained in prime go trials.

Response-specificity of stop tags

Our findings go beyond previous studies by allowing a test of whether stop associations code the information to withhold a response in an abstract, response-unspecific way or whether they refer to the particular response that had been stopped. As indicated by the findings of Experiments 2 and 3, repetition of an irrelevant stimulus feature that became associated with stopping in the prime led to generally slower reaction times, regardless of whether the required probe response was the same as or differed from the response that had been stopped in the prime.

This result is important in two respects: First, it argues against a response-specific tagging of the word's identity in prime stop trials. If this were the case, stimulus repetition should have caused a selective performance deficit only for those probe go trials that repeated the prime response, because the retrieved response-specific stop association would only have interfered with performing the same response again. However, interference effects were also found in probe go trials that required a different response, suggesting that the retrieved episode contains unspecific "stop" information. Second, we may also exclude the possibility that participants adopted a strategy and tried to improve their stop performance through preparing the alternative response (for a similar conclusion, see Verbruggen & Logan, 2008a; Verbruggen, Schneider, & Logan, 2008). According to this assumption, repeating irrelevant stimulus features after a prime stop trial would lead to retrieval of the opposing response, meaning that participants should have responded faster in prime–probe sequences with a response change than in sequences with response repetitions. Note that according to both alternative accounts, one would expect that repetition effects after prime stop trials would differ with respect to the response relation factor: For repetition of the prime word's identity as compared to baseline probe trials, retrieval of response-

specific stop associations would produce delayed probe go RT for response repetition sequences only, whereas retrieval of the alternative response would produce faster probe go RTs for response change sequences. However, the present findings conflict with both assumptions since for probe go trials that were preceded by prime stop trials the effect of response relation was effectively absent. Instead, we observed cost effects for response repetition and alternations alike if the stimulus's identity was repeated after successful prime stop trials. This global performance deficit supports the conclusion that irrelevant stimulus features were bound with and retrieved abstract stop associations.

We should also point out that the present finding of response-unspecific bindings between irrelevant stimulus features and stop information might reflect particular features of the stop task that was used in our experiments and might not necessarily reflect properties of stimulus-stop bindings in general. We used a simple stop task in which participants were required to stop *any* response once the stop signal occurs rather than a selective stop task. It is therefore possible that the present evidence for the assignment of global stop tags in Experiments 2 and 3 emerged because discrimination between responses was not part of the instructions of the stop task that we used (see also De Jong, Coles, & Logan, 1995; Verbruggen, Liefooghe, & Vandierendonck, 2005). In the motor variant of the selective stop task, however, stop signals refer to only a subset of the possible responses (e.g., participants are instructed to only stop left-hand responses, but not right-hand responses if the stop signal occurs; see Logan, 1994). Participants thus have to select a response before they know whether to stop it or not (Verbruggen et al., 2005), and the stop information is consequently more closely tied to the actual response code. It is an interesting question whether such a selective stop task would also yield selective stop tags: Coxon, Stinear, and Byblow (2007) argue that successful stopping in a selective stop task can be accomplished via engaging in a global stop mechanism first that nonselectively cancels all responses, followed by a reinitiating of the response if the stop signal was invalid. Several

additional studies indicate that such a nonselective stop mechanism with global effects on the motor system is likely to prevail in selective stop tasks (Aron & Verbruggen, 2008; Claffey, Sheldon, Stinear, Verbruggen, & Aron, 2010; Greenhouse, Oldenkamp, & Aron, 2012). Still, we do not want to rule out the possibility that specific stimulus-stop bindings can be established in some variant of the stop paradigm (e.g., if participants have foreknowledge of which response to stop, so that cognitive control is applied in advance and targeted selectively at a specific motor representation).

Relatedly, we would like to emphasize that although our findings converge with previous studies in providing evidence for response specificity in stimulus–response bindings (e.g., Frings et al., 2007; Hommel, 1998; Rothermund et al., 2005), we do not want to claim that this is always the case. There may be situations in which the global go-information is much more salient than the specific response information. For example, in a situation in which not responding is the default, differences between responses might tend to be ignored, and stimuli might instead become associated with global go-tags.

Stopping versus not responding

Another issue concerns the necessary requirements under which stimulus-stop associations are established. Our findings reveal that stopping a prepared action that is already on its way to being executed suffices to establish strong links between (irrelevant) stimulus features and stopping information. It is less clear whether similar stimulus-stop bindings would also emerge in situations in which no action tendency is elicited at all, and consequently no strong suppressive tendency is needed to counteract a response. Results in this regard are mixed: Previous studies using a simple go/no-go task have failed to reveal evidence for the emergence of stimulus–no-go associations if the mapping of stimuli and go/no-go cues varied unpredictably on a trial-by-trial basis (Mayr et al., 2009; Moeller & Frings, 2012). However, Verbruggen and Logan (2008a) yielded evidence for stimulus–no-go associations if stimuli were consistently paired

with no-go instructions during a training phase. Future research has to more systematically explore the conditions under which stimulus-stop associations are established.

"Stop" tags versus "stop responses"

A related question regards the nature of the stop information that is encoded and retrieved in an event file. Throughout this article we have described the stop information that is tied to irrelevant stimulus information as a tendency not to respond, and we have labelled the stop information that is included in an event file as a "stop" tag. We should point out, however, that our findings are also compatible with another description according to which stopping is just another response.[7] According to this account, retrieving such a "stop response" from the prime interferes with executing a go response in the probe, because a response conflict emerges between the required response and the retrieved "stop response"; similarly, retrieving a "stop response" from the prime has a beneficial effect on performance (more successful stopping) if the probe also requires a "stop response". The distinction between global and selective stopping that we addressed Experiments 2 and 3 can also be reframed in terms of a "stop response" account: It amounts to the question of whether stopping is just one response, regardless of which of the go responses has to be stopped, or whether stopping Response A is a different stopping response from stopping Response B.

As is evident from the previous remarks, theoretical accounts regarding the binding and retrieval of stop information in terms of a tendency "not to respond" and in terms of "stop responses" are empirically indistinguishable. We thus regard this question as a purely terminological issue for which there is no right or wrong position. Still, we prefer to describe our findings in terms of "stimulus-nonresponse" associations rather than as associations between stimuli and "stop responses". The main reason for this is that in a successful stop trial, there is no observable response. Put

simply, nothing has happened, and labelling this nonevent as a response might create the misleading implication that there is some positive, observable quality that indicates the occurrence of a stop response. Still, we are fully at ease with a description of our findings in terms of a binding/retrieval of stimuli and "stop responses" as long as this label is used in a way that makes it clear that what it refers to is not the execution of an observable response but rather the absence of an observable response after a response-eliciting stimulus has been presented.

The role of attention for binding stimulus and response features

In our view, stimulus-stop associations depict a special case of the broader class of stimulus–response binding and retrieval effects. The present findings illustrate that once an irrelevant stimulus (or feature) becomes integrated into an S–R episode, it gains access to and may retrieve not only response information, but also nonresponse information like recent (task) goals and context characteristics that were encoded simultaneously. This insight substantially extends early instance-based accounts like Logan's (1988; see also Boronat & Logan, 1997; Logan & Etherton, 1994), which held the view that the encoding, storage, and retrieval of S–R episodes is an obligatory consequence of attention directed to stimuli and responses. The occurrence of binding effects for irrelevant stimuli (which by definition do not lie at the centre of attention) seems to be at odds with this account. However, several recent studies together with the present experiments demonstrate that even irrelevant stimulus aspects of a given situation may become part of S–R episodes (e.g., Frings & Rothermund, 2011; Frings et al., 2007; Giesen & Rothermund, 2011; Rothermund et al., 2005); moreover, Giesen et al. (2012) found binding effects even for interfering distractor stimuli although they became subjected to selective inhibitory processes. These findings suggest that attention is a sufficient, but not necessary

---

[7] We thank Andrea Philipp for drawing our attention to this important distinction.

prerequisite for the episodic integration of stimulus and response codes (see also Hommel, 2005). However, the present study was not specifically designed to investigate the issue of attention, since relevant and irrelevant features were part of the same visual object in our experiments. Future research is therefore needed to examine whether the binding of stop information still applies to objects that are outside of the attentional focus and are spatially separated from the target object. Recent studies suggest that there may be limits to the integration of irrelevant information into stimulus–response episodes and that general principles of Gestalt formation and affective matching may apply also to processes of S–R binding and retrieval (Frings & Rothermund, 2011; Giesen & Rothermund, 2011).

CONCLUSION

In the present experiments, we created a situation in which top-down processes that exert cognitive control to intervene with a current course of action can be contrasted with stimulus-driven processes that rely on short-term S–R episodes to regulate behaviour. An important conclusion we draw from the obtained results is that these processes effectively act in concert, rather than opposing each other. That is, according to Logan and Cowan (1984; see also Verbruggen & Logan, 2008a), the stopping of a response may be achieved by changing the current course of action from the goal to "respond" to the goal to "stop". Current goals, in turn, constitute important contextual characteristics that are temporarily stored together with encountered stimuli and responses (Hommel, 1998, 2004; Logan, 1988). In principle then, both respond and stop goals may become elements of such a processing episode and can be retrieved automatically from memory once an element of the episode is repeated. In the former case, the retrieved episode will contain information of the presented stimuli, the goal to respond, and the executed response, while in the latter, the retrieved episode should only contain information of the presented stimuli and the stop

goal (since execution of the response was successfully suppressed).

The integration of stimuli with unspecified, abstract stop associations provides our cognitive system with the flexibility to adapt quickly to changing environments while at the same time, it takes advantage of repeated co-occurrences of stimuli and incorporates them for automatic behaviour regulation. After all, a red traffic light is a red traffic light, regardless of whether you are standing at the sidewalk or sitting in your car; what matters most is that you interrupt your current movement. However, associating the red light with the specific information "do not move your feet anymore" would bring you in a hazardous situation once you sit in your car and are forced to put on the brakes. Associating the red light with the more abstract goal to stop proceeding, however, gives you the flexibility to select the most appropriate response with respect to that goal.

REFERENCES

Aron, A. R., & Verbruggen, F. (2008). Stop the presses: Dissociating a selective from a global mechanism for stopping. *Psychological Science*, 19(11), 1146–1153. doi:10.1111/j.1467-9280.2008.02216.x

Bissett, P. G., & Logan, G. D. (2011). Balancing cognitive demands: Control adjustments in the stop-signal paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 37(2), 392–404. doi:10.1037/a0021800

Boronat, C. B., & Logan, G. D. (1997). The role of attention in automatization: Does attention operate at encoding, or retrieval, or both? *Memory & Cognition*, 25(1), 36–46. doi:10.3758/BF03197283

Claffey, M. P., Sheldon, S., Stinear, C. M., Verbruggen, F., & Aron, A. R. (2010). Having a goal to stop action is associated with advance control of specific motor representations. *Neuropsychologia*, 48(2), 541–548. doi:10.1016/j.neuropsychologia.2009.10.015

Colzato, L. S., van Wouwe, N. C., & Hommel, B. (2007). Feature binding and affect: Emotional modulation of visuo-motor integration.

Neuropsychologia, *45*(2), 440–446. doi:10.1016/j. neuropsychologia.2006.06.032

Coxon, J. P., Stinear, C. M., & Byblow, W. D. (2007). Selective inhibition of movement. *Journal of Neurophysiology*, *97*(3), 2480–2489. doi:10.1152/ jn.01284.2006

De Jong, R., Coles, M. G. H., & Logan, G. D. (1995). Strategies and mechanisms in nonselective and selective inhibitory motor control. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 498–511. doi:10.1037/0096-1523.21.3.498

Denkinger, B., & Koutstaal, W. (2009). Perceive-decide-act, perceive-decide-act: How abstract is repetition-related decision learning? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(3), 742–756. doi:10.1037/a0015263

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. doi:10.3758/BF03193146

Frings, C., & Rothermund, K. (2011). To be or not to be … included in an event file: Integration and retrieval of distractors in stimulus–response episodes is influenced by perceptual grouping. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1209–1227. doi:10.1037/a0023915

Frings, C., Rothermund, K., & Wentura, D. (2007). Distractor repetitions retrieve previous responses to targets. *The Quarterly Journal of Experimental Psychology*, *60*(10), 1367–1377. doi:10.1080/ 17470210600955645

Garner, W. R., & Felfoldy, G. L. (1970). Integrality of stimulus dimensions in various types of information processing. *Cognitive Psychology*, *1*(3), 225–241. doi:10.1016/0010-0285(70)90016-2

Gibbons, H., & Stahl, J. (2008). Early activity in the lateralized readiness potential suggests prime-response retrieval as a source of negative priming. *Experimental Psychology*, *55*(3), 164–172. doi:10.1027/1618-3169.55.3.164

Giesen, C., Frings, C., & Rothermund, K. (2012). Differences in the strength of distractor inhibition do not affect distractor-response bindings. *Memory & Cognition*, *40*(3), 373–387. doi:10.3758/s13421-011-0157-1

Giesen, C., & Rothermund, K. (2011). Affective matching moderates S–R binding. *Cognition and Emotion*, *25*(2), 342–350. doi:10.1080/02699931. 2010.482765

Greenhouse, I., Oldenkamp, C. L., & Aron, A. R. (2012). Stopping a response has global or nonglobal effects on the motor system depending on preparation. *Journal of Neurophysiology*, *107*(1), 384–392. doi:10.1152/jn.00704.2011

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus–response episodes. *Visual Cognition*, *5*(1), 183–216. doi:10.1080/713756773

Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences*, *8*(11), 494–500. doi:10.1016/j.tics.2004. 08.007

Hommel, B. (2005). How much attention does an event file need? *Journal of Experimental Psychology: Human Perception and Performance*, *31*(5), 1067–1082. doi:10.1037/0096-1523.31.5.1067

Horner, A. J., & Henson, R. N. (2009). Bindings between stimuli and multiple response codes dominate long-lag repetition priming in speeded classification tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(3), 757–779. doi:10.1037/a0015262

Horner, A. J., & Henson, R. N. (2011). Stimulus–response bindings code both abstract and specific representations of stimuli: Evidence from a classification priming design that reverses multiple levels of response representation. *Memory & Cognition*, *39* (8), 1457–1471. doi:10.3758/s13421-011-0118-8

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*(4), 492–527. doi:10.1037/0033-295X.95.4.492

Logan, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA: Academic Press.

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*(3), 295–327. doi:10.1037/0033-295X.91.3.295

Logan, G. D., & Etherton, J. L. (1994). What is learned during automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(5), 1022–1050. doi:10.1037/0278-7393.20.5.1022

Mayr, S., & Buchner, A. (2006). Evidence for episodic retrieval of inadequate prime responses in auditory negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(4), 932–943. doi:10.1037/0096-1523.32.4.932

Mayr, S., Buchner, A., & Dentale, S. (2009). Prime retrieval of motor responses in negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 408–423. doi:10.1037/0096-1523.35.2.408

Moeller, B., & Frings, C. (2011). Remember the touch: Tactile distractors retrieve previous responses to targets. *Experimental Brain Research*, *214*(1), 121–130. doi:10.1007/s00221-011-2814-9

Moeller, B., & Frings, C. (2012). *Driver assistance designers beware: Distractor-response bindings influence response times to local danger warnings*. Manuscript submitted for publication.

Moeller, B., Rothermund, K., & Frings, C. (2012). Integrating the irrelevant sound: Grouping modulates the integration of irrelevant auditory stimuli into event files. *Experimental Psychology*, *59*(5), 258–264. doi:10.1027/1618-3169/a000151

Neill, W. T., & Valdes, L. A. (1992). Persistence of negative priming: Steady state or decay? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(3), 565–576. doi:10.1037/0278-7393.18.3.565

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(5), 993–1000. doi:10.1037/0278-7393.18.5.993

Pösse, B., Waszak, F., & Hommel, B. (2006). Do stimulus–response bindings survive a task switch? *European Journal of Cognitive Psychology*, *18*(4), 640–651. doi:10.1080/09541440500423285

Rieger, M., & Gauggel, S. (1999). Inhibitory after-effects in the stop signal paradigm. *British Journal of Psychology*, *90*(4), 509–518. doi:10.1348/000712699161585

Rothermund, K., Eder, A. B., & Frings, C. (2013). *Integration of affective outcomes with actions and situations: Negative feedback prevents retrieval of response information from S–R episodes*. Manuscript submitted for publication.

Rothermund, K., Wentura, D., & De Houwer, J. (2005). Retrieval of incidental stimulus–response associations as a source of negative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(3), 482–495. doi:10.1037/0278-7393.31.3.482

Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison-Wesley.

Verbruggen, F., Liefooghe, B., & Vandierendonck, A. (2005). On the difference between response inhibition and negative priming: Evidence from simple and selective stopping. *Psychological Research*, *69*(4), 262–271. Retrieved from 10.1007/s00426-004-0177-6

Verbruggen, F., & Logan, G. D. (2008a). Long-term aftereffects of response inhibition: Memory retrieval, task goals, and cognitive control. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(5), 1229–1235. doi:10.1037/0096-1523.34.5.1229

Verbruggen, F., & Logan, G. D. (2008b). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General*, *137*(4), 649–672. doi:10.1037/a0013170

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*(2), 413–426. doi:10.1037/0096-1523.34.2.413

Verbruggen, F., Schneider, D. W., & Logan, G. D. (2008). How to stop and change a response: The role of goal activation in multitasking. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(5), 1212–1228. doi:10.1037/0096-1523.34.5.1212

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*(4), 361–413. doi:10.1016/S0010-0285(02)00520-0

Waszak, F., Hommel, B., & Allport, A. (2005). Interaction of task readiness and automatic retrieval in task switching: Negative priming and competitor priming. *Memory & Cognition*, *33*(4), 595–610. doi:10.3758/BF03195327

Waszak, F., & Pholulamdeth, V. (2009). Episodic S–R bindings and emotion: About the influence of positive and negative action effects on stimulus–response associations. *Experimental Brain Research*, *194*(3), 489–494. doi:10.1007/s00221-009-1745-1