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Prime Retrieval of Motor Responses in Negative Priming

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Three auditory identification experiments were designed to specify the prime–response retrieval model of negative priming (S. Mayr & A. Buchner, 2006), which assumes that the prime response is retrieved in ignored repetition trials and interferes with probe responding. In Experiment 1, shortly before (in Experiment 1A) or after (in Experiment 1B) the prime, a cue signaled whether participants were to respond (*go* trials) or not (*no–go* trials) to the prime. Negative priming was found in either case. A *prime–response retrieval effect*—an increase in prime response errors to the probe targets of ignored repetition trials—was found for go trials only. In Experiment 2, prime trials with go cues always demanded a response, whereas the response to no–go trials depended on motor discrimination: For left- (right-) hand responses, the response had to be withheld (valid no–go); for right- (left-) hand responses, the response had to be executed (invalid no–go). The prime–response retrieval effect was present only for go and invalid no–go trials. This implies that execution of the prime response is a precondition for prime–response retrieval, whereas a response preparation plan and a response description in task-specific terms are not sufficient.

Keywords: negative priming, prime–response retrieval, motor responses, go/no–go task

In 1992, Neill and colleagues (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) proposed the episodic retrieval model of negative priming. Following this account, the slowed-down and more error-prone responding to previously ignored stimuli is caused by a memory mechanism. The current probe target stimulus cues the retrieval of the recent prime episode in which the same stimulus functioned as a distractor stimulus. Nonresponse information that is attached to the prime distractor is retrieved. The retrieved nonresponse information is in conflict with the current probe requirement to respond to the same stimulus as a target. This conflict impedes fast processing and responding to the stimulus. There is increasing evidence that the backward-acting memory-based episodic retrieval model is a more adequate model to explain the negative priming effect than the originally proposed distractor inhibition model (for a review, see Mayr & Buchner, 2007). The latter model assumes a forward-acting suppression mechanism of to-be-ignored distractor representations and/or a blocking of the translation into a response code (Houghton & Tipper, 1994; Tipper, 1985, 2001; Tipper & Cranston, 1985). However, the two models are not mutually exclusive (May, Kane, & Hasher, 1995; Tipper, 2001).

According to the original episodic retrieval model (Neill & Valdes, 1992; Neill et al., 1992), recalling the inappropriate nonresponse information attached to the prime distractor is responsible for the emerging conflict about whether to respond (current probe requirement) or not to respond (former prime requirement) to the probe target. In contrast to this original nonresponse retrieval variant, the prime–response retrieval variant of the episodic retrieval model (Mayr & Buchner, 2006) postulates that the response associated with the prime target is retrieved in ignored repetition trials. The prime response is inappropriate for responding to the probe target and elicits a time-consuming response conflict.

Both the original and the prime–response retrieval variants are based on the same core aspect of the episodic retrieval model, in that they postulate the retrieval of the prime episode cued by the probe target in ignored repetition trials but not in control trials. The two variants differ in what they assume to be the retrieved inappropriate prime episode information.

Mayr and Buchner (2006, Experiments 2 and 3) provided evidence for the prime–response variant and against the nonresponse variant in a four-alternative identification task in which every stimulus required a unique response. The authors took advantage of the fact that the prime–response variant allows the derivation of a unique prediction about the relative frequencies of the different probe error types. Simply put, the prime–response variant predicts that incorrect repetitions of the prime response as a reaction to the probe target should be overrepresented in the error rates of ignored repetition trials. The nonresponse model, however, cannot explain why one should expect an increase specifically in the probability of incorrectly retrieved prime responses. As predicted by the prime–response retrieval variant, both experiments—Experiment 2 was an auditory identification task, and Experiment 3 was a replication in the visual modality—revealed an increased probability of incorrect repetitions of the prime response as a reaction to the probe target for ignored repetition trials compared to control trials. This finding has since been replicated in both modalities (Hauke, Mayr, Buchner, & Niedeggen, 2008). Note that this find-

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ing is also incompatible with the distractor inhibition account (Houghton & Tipper, 1994; Tipper, 1985, 2001; Tipper & Cranston, 1985). A reduced activation of the former prime distractor representation cannot be responsible for an increase in repetitions of the prime response. Rothermund, Wentura, and De Houwer (2005) proposed a model very similar to the prime–response retrieval variant, which they called the stimulus–response retrieval model. In a series of four task-switching experiments they provided evidence for this model by showing that negative priming was inverted to positive priming when the prime and probe required the same response, whereas negative priming was found when different responses were required in prime and probe.

Figure 1 depicts a multinomial processing tree model (cf. Hu & Batchelder, 1994) used by Mayr and Buchner (2006) to evaluate the prime–response retrieval variant against the nonresponse retrieval variant of the episodic retrieval account. This model is also of central importance to the experiments presented in this article. The model represents the processing stages that are assumed to be involved in generating a probe response for both the ignored repetition (upper part of Figure 1) and the control condition (lower part of Figure 1). With probability *ci* participants correctly identify the probe target and respond to it without making an error. Selecting the probe target against the probe distractor is difficult. If an error occurs (with probability $1 - ci$), it will predominantly do so because of the confusion of the probe target with the probe distractor. Probe–stimulus confusion occurs with the conditional probability *psc* and leads to incorrect probe distractor responses.

If probe–stimulus confusion does not dominate responding (with probability $1 - psc$), then, with probability *prr*, prime–response retrieval may occur and lead to incorrect prime target responses. This is the critical stage for which prime–response retrieval and nonresponse retrieval variants of the episodic re-

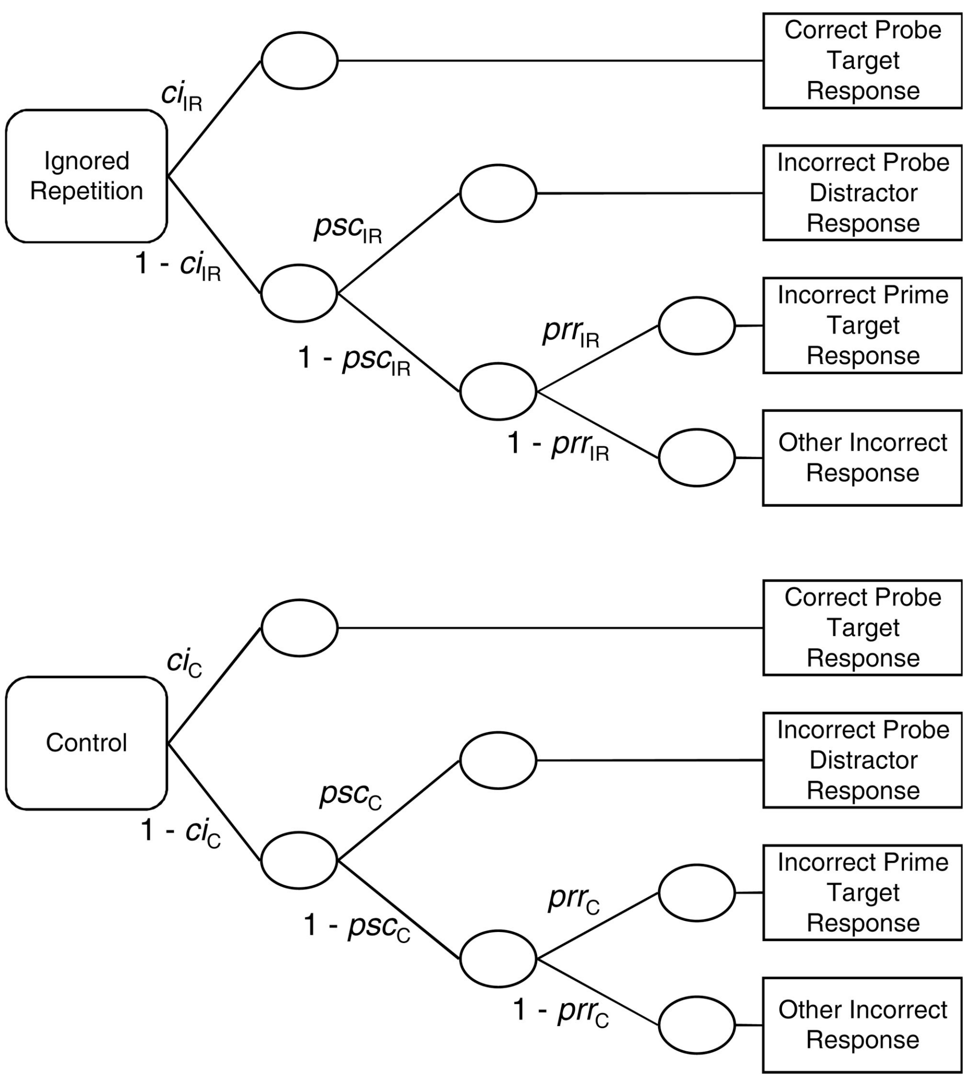

Figure 1. Multinomial processing tree model (prime–response retrieval model) for analyzing the probe reactions in the trial type conditions ignored repetition (IR; upper portion) and control (C; lower portion). For details see text. *ci* = probability of correctly identifying the probe target and responding to it without error; *psc* = probability of probe–stimulus confusion; *prr* = probability of prime–response retrieval.

trieval model make different predictions with respect to the processes that generate overt behavior. The probability of retrieving a prime response in the ignored repetition condition, prr_{IR}, is expected to be larger than prr_C (the probability of retrieving a prime response in the control condition) if the prime–response retrieval variant is correct but not if only the nonresponse retrieval variant of the episodic retrieval account is correct. Thus, if the goodness-of-fit test of the restricted model assuming $prr_{IR} = prr_C$ leads to a significant misfit, then this is evidence in favor of the prime–response retrieval variant of the episodic retrieval model. For completeness, if none of the processes mentioned so far dominates responding, the person inevitably reacts (with probability $1 - prr$) with the only remaining incorrect response.

The experiments of Mayr and Buchner (2006) and of Hauke et al. (2008) demonstrated that prime–response retrieval takes place in the processing of ignored repetition trials. The experiments reported in this article were conducted in order to further test, extend, and specify the prime–response retrieval variant of the episodic retrieval model. To this end, a manipulation of the prime response requirement was chosen. In trials that required the execution of a prime response (henceforth *go* trials, equivalent to the trials in Experiment 2 and 3 of Mayr & Buchner, 2006), this particular response should be encoded as part of the stored prime episode. If the prime–response retrieval model is valid, then prime–response retrieval should take place in the subsequent probe presentation for ignored repetition trials. As a consequence, we expected to find an increase in the probability of repeated prime responses for the ignored repetition trials compared to the control trials; that is, we expected a prime–response retrieval effect. In contrast to the go trials, a prime response is prohibited for the *no–go* trials. Consequently, no prime response information should be encoded in the prime episode, which is why no prime response can be retrieved in ignored repetition probe trials. The prime–response retrieval model thus predicts no increase in the probability of repeated prime responses for ignored repetition trials. The predictions are different for the original variant of the episodic retrieval model and for the distractor inhibition model. Both models make no statement about responses to attended primes and thus cannot predict a difference in prime–response retrieval errors as a function of the go/no–go manipulation. Therefore, the finding of a prime–response retrieval effect in go trials, but no prime–response retrieval effect in no–go trials, can be counted as additional evidence in favor of the prime–response retrieval variant of the episodic retrieval model of negative priming.

These predictions were tested in Experiments 1A and 1B. Additionally, a manipulation of the prime response requirement should be indicative of the importance of the prime–response retrieval mechanism for the emergence of the classical negative priming effect in reaction times and overall error rates. So far, we do not know whether prime–response retrieval is the sole mechanism eliciting the negative priming effect or whether this mechanism is just one of several mechanisms that bring about the effect. It is also conceivable that in addition to the prime–response retrieval mechanism the retrieval of nonresponse tags (as proposed in the original episodic retrieval model) or inhibitory processes or both contribute to the overall size of the negative priming effect.

Assuming that the prime–response retrieval mechanism was inactive in no–go trials (to anticipate, the results of Experiments 1A and 1B were consistent with this assumption), then the negative priming effect in terms of reaction times and overall error rates should be absent for no–go trials if prime–response retrieval is the sole mechanism to induce negative priming.

Experiment 1A

Participants performed a modified version of the auditory four-choice identification task used in Experiment 2 of Mayr and Buchner (2006). It differed in that trials could be either go trials requiring a prime response or no–go trials requiring a prime response be withheld. Probe presentations always required a response. We expected a prime–response retrieval effect for the go condition but not for the no–go condition.

Method

Participants. Participants were 127 adults (mostly students), 83 women and 44 men. They ranged in age from 17 to 43 years ($M = 24.73$, $SD = 5.40$). Forty additional participants did not reach one of the two learning criteria of 75% correct reactions in the first training phase or of 60% correct reactions in the second training phase. For 10 further participants there was at least one condition with less than 10 valid probe reactions, which was defined as the minimum for calculating reliable averages. The data of these participants were also discarded. This dropout rate is higher than what we usually observe and most likely is due to a particular combination of circumstances. First, the task was more difficult than in our previous experiments in that participants had to manage the switching between the go and no–go trials in addition to the sound identification task. Second, participants had to pass criteria for two separate training phases rather than for just one (see below). Third, participants knew in advance that they would receive their payments even if they failed during one of the training phases, which may have affected their willingness to cope with the difficult task. Fourth, an unusually large amount of people were not native speakers of German and had difficulties with the instructions. Fortunately, Experiment 1B had a much lower dropout rate but very similar results, so the dropout rate does not seem to be a problem for the results reported here. Participants were paid €8.00 for their participation.

Materials. The stimuli were four digitized tones (of a frog, piano, drum, and bell). Each tone was 300 ms long, complete with attack and decay. Participants heard the tones over earphones that were fitted with noise-insulation covers and plugged directly into an Apple iMac computer.

A 20-ms metronome click indicated the ear (left or right) at which the to-be-attended tone would be presented. Reactions were registered by a response box, which was directly plugged into the computer. The four tones were assigned to four sagitally aligned buttons of the response box. Participants were instructed to press the two more distal buttons with the middle and index fingers of their right hand and the two more proximal buttons with the middle and index fingers of their left hand. The buttons were labeled with the color of the drawing associated with each respective tone (green for frog, white for piano, blue for drum, and red for bell).

Each experimental trial consisted of a prime and a probe presentation. Each presentation consisted of a target presented to one ear and a simultaneously presented distractor at the other ear. Ignored repetition trials were constructed by randomly selecting three of the four different stimuli as prime and probe targets and distractors, with the restriction that the ignored prime had to be identical to the attended probe (left-most column of Table 1). Next, parallel control trials were constructed by replacing the ignored prime with the remaining stimulus (*piano* replaced by *bell* in the example displayed in Table 1). Within these two types of trials the ignored prime would have been the correct probe response in 50% of the trials, and the prime response would never have been equal to the probe response. Filler trials were constructed to compensate for this by randomly selecting three of the four different types of stimuli as prime and probe targets and distractors with the restriction that the attended prime had to be identical to the attended probe (labeled *Attended repetition filler* in Table 1). Additional filler trials (labeled *Control filler* in Table 1) were constructed by replacing, in the attended repetition filler trials, the attended prime with the remaining stimulus. For the entire set of stimuli, the correct probe reaction could not be inferred from the prime response.

Note that an ignored repetition trial always shared its control trial with an attended repetition filler trial (see Table 1 for an example). If we had used the entire set of trials that can be generated by the algorithm just described, then every control trial would have occurred twice. In order to avoid this confound for control trials, ignored and attended repetition trials were systematically assigned to Set 1 or Set 2, with three restrictions: First, identical control trials had to belong to different sets. Second, within each trial type, the frequencies of the different tones had to be identical. Third, the frequencies of the combinations of attended and ignored tones, both within the prime and within the probe pairs, had to be equal for the different trial types. Sets 1 and 2 were completely parallel with respect to the second and the third restrictions. For each set, the required prime response did not predict the required probe response. Participants were randomly assigned to Set 1 or Set 2. We tested 65 participants with Set 1 and 62 participants with Set 2.

Visual task cues were presented before the auditory prime and probe cues. They indicated whether participants had to react (in the go condition) or to withhold a response (in the no–go condition) to the next presentation. A black circle with a green walking man inside—similar to the "walk" sign of a pedestrian traffic light—was the cue that prompted a reaction to the following auditory presentation. Analogously, a black circle with a red standing man inside—similar to the "stop" sign of a pedestrian traffic light—indicated that a response should be withheld to the upcoming presentation. The visual task cues were presented in the center of the screen. Their diameter was about 90 mm (which corresponds to a viewing angle of 7.3°).

Each set of 48 unique trials (12 trials of each of the four trial types: ignored repetition, control, attended repetition filler, and control filler) was once implemented in the go condition and once implemented in the no–go condition. Throughout the entire experiment, the trials were presented four times, resulting in 384 experimental trials, which were presented in an individually randomized sequence. For each trial, the attentional allocation (left in prime and right in probe versus right in prime and left in probe) was randomly assigned.

Procedure. Participants were familiarized with the sound stimuli. Next, participants heard and reacted to pairs of tones. A metronome click indicated the randomly selected ear at which the to-be-attended tone would be presented. Following a 400-ms click–target interval, a randomly selected target tone was presented at that ear and a to-be-ignored distractor was presented simultaneously to the other ear. Participants reacted to the target sound by quickly pressing the corresponding response button. They were given feedback about the correctness of each reaction, after which they initiated the next trial. The tone–response association was presented in the upper left corner of the display during the first 75 training trials. Participants entered the next training phase only if more than 75% of the preceding 30 responses had been correct. Participants who did not reach this criterion within 150 trials were given the choice to quit the experiment or to start again with the training. Virtually all participants who did not reach the criterion decided to quit.

Next, participants were introduced to the visual task cues preceding the trials. They were told that either a green traffic light or a red traffic light would precede each auditory stimulus presentation and would signal that a response had to be given or to be withheld, respectively. In the next training phase, prime and probe pairs were presented. The prime pair could be preceded by either a green or a red traffic light. The probe pair was always preceded by a green traffic light. After each prime–probe trial, participants received feedback about the correctness of their responses. The subsequent training trial started automatically. Participants entered the experiment proper when they had responded correctly in more than 60% of the preceding 45 training responses. For participants who did not reach this criterion within 150 trials, the experiment was aborted at that stage.

Instructions to the experiment proper introduced an additional task. Participants were informed that a single additional tone would occasionally be played after the probe response. Participants had to judge whether this tone had been the prime target of the current trial. This control question was intended to increase attention to the prime tones, even when no response had to be carried out. The presented tone was always played on the attended prime

Table 1
Examples of Stimulus Configurations and Required Responses Used in Experiments 1A, 1B, and 2

	Ignored repetition		Control		Attended repetition filler		Control filler	
Variable	Attended ear	Ignored ear	Attended ear	Ignored ear	Attended ear	Ignored ear	Attended ear	Ignored ear
Prime	Frog	Piano	Frog	Bell	Piano	Bell	Frog	Bell
Required response	*Frog*		*Frog*		*Piano*		*Frog*	
Probe	Piano	Drum	Piano	Drum	Piano	Drum	Piano	Drum
Required response	*Piano*		*Piano*		*Piano*		*Piano*	

side. If the tone was identical to the prime target tone, participants had to press a button on the left and below the regular response buttons. If the tone was different from the prime target tone, they had to press a button on the right and below the regular response buttons. To facilitate the task, the spatial arrangement of the two buttons (*yes*, i.e., identical, on the left; *no*, i.e., different, on the right) was presented on the screen until the participant had responded. To familiarize participants with this task, we exposed them to five trials with the additional control question. In the experiment proper 25% of randomly selected trials were followed by the control question. In approximately 25% of these trials the correct answer was *yes* (identical); in about 75% it was *no* (different).

Each of the 384 experimental trials began with the presentation of the visual task cue, 150 ms after which the metronome click was played. After a 400-ms click–target interval, the prime pair of tones was presented. Then 2,000 ms after the prime tone onset, the visual task cue for the prime was replaced by the visual probe cue. Another 150 ms after the visual probe cue, the click that cued the to-be-attended probe was presented. The probe click (presented to the opposite of the prime target presentation side) was followed by a 400-ms click–target interval, after which the probe pair of tones was presented. Within 1,800 ms after the onset of the prime stimuli and for 3,000 ms after the onset of the probe stimuli, participants had to respond, given that responding was allowed. After each prime–probe trial participants were given auditory and visual feedback about their performance. Prime responses in no–go trials, prime responses in go trials slower than 1,800 ms, and probe responses slower than 3,000 ms were counted as invalid. Invalid responses were not repeated. After trial feedback, a 2,200-ms intertrial interval followed before the visual task cue of the next trial was presented. After every 20th trial, participants received a summary feedback in terms of the score they had reached by this time. After the final trial, all participants were informed about the purpose of the experiment. The experiment took about 90 min.

Design. The experiment comprised a two-factor design with trial type (ignored repetition vs. control) as well as prime response (go vs. no–go) as within-subjects variables. The dependent variable of greatest interest was the probe error frequency, accumulated across participants, but we also analyzed participants' average reaction times and overall probe error rates. For the analyses of reaction times and overall error rates in this and the following experiments, we used a multivariate approach for all within-subjects comparisons. For all three experiments, the multivariate test criteria correspond to the same (exact) *F* statistic, which is reported.

The critical variable for the a priori power analysis was the comparison of the *prr* parameter between the ignored repetition and control condition. The effects reported by Mayr and Buchner (2006) were rather heterogeneous in size. We estimated the population effect size as the average sample effect size of their experiments, that is, $w = 0.0415$. The following calculations were based upon the (realistic, as it turned out) estimate that each participant would contribute approximately 80 utilizable probe responses in the go condition as well as in the no–go condition (i.e., about 40 responses in each ignored repetition and control condition). Under these conditions and assuming desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of $N = 95$ participants (Faul, Erdfelder, Lang, & Buchner, 2007). We were able to collect data from $N = 127$ participants so that the power was actually even larger than what we had planned for ($1 - \beta = .99$).

To test whether the size of the negative priming effect in response times (and overall error rates) was influenced by the prime response variable, we examined the interaction between trial type and prime response. Given a population correlation of $\rho = .7$ between the difference variables of reaction times (ignored repetition vs. control) in the two levels of the prime response variable (or vice versa) and desired levels of $\alpha = \beta = .05$, a sensitivity analysis revealed that we were able to detect effects of size $f = 0.12$ (between small and medium effects as defined by Cohen, 1988). This corresponds to assuming $\eta^2 = .09$ as the population effect size.

Results

For this and the following experiments, the multinomial analysis of the prime–response retrieval effect is reported first. Second, reaction time and overall error negative priming effects are described. Finally, an analysis of the control question is reported.

The frequency data for each response category are displayed in the upper half of Table 2. The multinomial model displayed in Figure 1 fit the frequency data of Experiment 1A perfectly. The parameter estimates of the critical retrieval process (prr_{IR} and prr_C) are illustrated for the two levels of the prime response variable in the left half of Figure 2. In order to test the prime–response retrieval variant of the episodic retrieval account against the nonresponse variant, we tested, for the go as well as for the no–go condition, the goodness-of-fit test of the model with the restriction that $prr_{IR} = prr_C$, which is implied by the nonresponse variant. The restricted model did not fit the data for the go condition, $G^2(1) = 47.26$, $p < .01$, $w = 0.0688$, and had to be rejected. However, the model could not be rejected for the no–go condition, $G^2(1) = 0.13$, $p = .72$, $w = 0.0033$.

Probe reactions were evaluated only for trials in which both the prime and the probe reactions were correct and not faster than 100 ms. The left half of Figure 3 (Panel A) shows that the mean reaction times (based on the individual mean reaction times) were larger in the ignored repetition than in the control condition. Probes were responded to faster after prime responses had been withheld in no–go trials in comparison to go trials. Descriptively, the negative priming effect was larger in the go than in the no–go condition.

A 2 × 2 multivariate analysis of variance (MANOVA) of the reaction time data with trial type (ignored repetition vs. control) and prime response (go vs. no–go) as within-subjects variables showed a significant main effect of trial type, $F(1, 126) = 37.16$, $p < .01$, $\eta^2 = .23$, and of prime response, $F(1, 126) = 8.77$, $p < .01$, $\eta^2 = .07$. The interaction of trial type and prime response was also significant, $F(1, 126) = 6.69$, $p = .01$, $\eta^2 = .05$. Negative priming was significant at both levels of the prime response variable, as is shown by follow-up tests wherein we used the Bonferroni–Holm method of protecting against alpha error accumulation (Holm, 1979)[1]; for the go condition, $t(126) = 5.69$, $p <$

[1] The Bonferroni–Holm method of protecting against alpha error accumulation was applied to all post hoc tests reported in this article that compare the ignored repetition and control conditions within the levels of the prime response variable. Depending on whether the prime response variable was composed of two levels (Experiments 1A and 1B) or three levels (Experiment 2), local alpha levels were set either to .025 and .05 (Experiments 1A and 1B) or to .017, .025, and .05 (Experiment 2) for multiple testing.

Table 2
Accumulated Absolute Frequencies of Correct Probe Responses and of the Different Types of Probe Errors for the Ignored Repetition Condition and the Control Condition in Experiments 1A and 1B

	Experiment 1A			
	Go		No–go	
Response	Ignored repetition	Control	Ignored repetition	Control
Correct probe target responses	4,098	4,348	4,753	4,818
Incorrect probe distractor responses	527	447	676	651
Incorrect prime target responses	218	49	221	205
Other incorrect responses[a]	157	130	260	230
	Experiment 1B			
	Go		No–go	
Response	Ignored repetition	Control	Ignored repetition	Control
Correct probe target responses	2,638	2,731	2,936	2,958
Incorrect probe distractor responses	171	131	155	139
Incorrect prime target responses	51	8	24	19
Other incorrect responses[a]	24	29	25	24

[a] In ignored repetition trials, this response category comprised responses with the key that was assigned to the nonpresented stimulus. In control trials, this response category comprised responses with the key that was assigned to the prime distractor stimulus.

.01 (adjusted $\alpha_{\text{local}} = 0.025$), $\eta^2 = .20$; for the no–go condition, $t(126) = 2.82$, $p < .01$ (adjusted $\alpha_{\text{local}} = 0.05$), $\eta^2 = .06$.

An analogous 2 × 2 MANOVA of the error data (Panel B of Figure 3, left half) showed a similar pattern of results. The main effects of trial type and prime response were significant, $F(1, 126) = 38.07$, $p < .01$, $\eta^2 = .23$, and $F(1, 126) = 13.01$, $p < .01$, $\eta^2 = .09$, respectively. Again, the interaction of both variables was also significant, $F(1, 126) = 14.35$, $p < .01$, $\eta^2 = .10$. Negative priming was significant for the go condition, $t(126) = 6.82$, $p < .01$, $\eta^2 = .27$, but not for the no–go condition, $t(126) = 1.52$, $p = .13$, $\eta^2 = .02$.

To analyze performance in the control question, we used the two-high-threshold model (cf. Snodgrass & Corwin, 1988, Equations 7 and 8).[2] Figure 4 represents the mean estimates of P_r and B_r which reflect participants' discrimination performance and response bias, respectively. Before computing the indices of sensitivity and bias, hit and false alarm rates were adjusted as suggested by Snodgrass and Corwin (1988). In the experiment, 25% of the trials were randomly selected and followed by a test tone. Also randomly selected, in approximately 25% of these trials, the test tone was identical to the prime target tone and the correct answer was *yes*. In about 75% of the trials a different test tone was presented with the correct answer being *no*. As a consequence, not every participant was necessarily exposed to the control question in each of the eight possible categories: 2 (go vs. no–go) × 2 (ignored repetition vs. control) × 2 (identical tone vs. different tone). The following analyses were performed only for those participants who provided responses in each of the relevant categories.

Participants demonstrated increased discrimination performance in go trials compared to no–go trials, whereas the trial type manipulation was of no importance for discrimination performance. For the sensitivity index, P_r, there was a significant main effect of prime response, $F(1, 97) = 30.29$, $p < .01$, $\eta^2 = .24$, but neither a main effect of trial type, $F(1, 97) = 0.26$, $p = .61$, $\eta^2 < .01$, nor an interaction between the two variables, $F(1, 97) = 2.36$, $p = .13$, $\eta^2 = .02$.

Follow-up tests showed that the two trial type conditions differed neither in the go condition, $t(107) = 1.36$, $p = .18$, $\eta^2 = .02$, nor in the no–go condition, $t(115) = -0.25$, $p = .80$, $\eta^2 < .01$. In addition, discrimination performance was significantly better than zero for both trial types in the go condition, $t(117) = 19.95$, $p <$

[2] Following Snodgrass and Corwin (1988), threshold models are formal models to assess recognition memory. Different from signal detection models, they postulate discrete memory states and not a continuum of memory strength. The two-high-threshold model assumes that old items either exceed an internal threshold of being identified as old or that they do not exceed this threshold and their memory states remain uncertain. Similarly, new items that exceed the internal threshold for new items are always identified as being new; otherwise their origin is uncertain. Consequently, there are three memory states: recognition as old, recognition as new, and uncertainty. Old items never exceed the threshold for recognition as new, whereas new items cannot exceed the threshold for recognition as old. Items of uncertain state are classified as old or new on the basis of the participant's response bias. Under the assumption that both thresholds are equal, this common threshold P_r functions as a discrimination index. Given that hits are composed of true recognitions (P_r) and correct guesses (estimable from the false alarm rate), P_r can be calculated as P_r = hits – false alarms (Equation 7 in Snodgrass and Corwin, 1988, p. 38). The probability of saying "old" to an uncertain item occurs with a probability that is represented by a response bias parameter, B_r. For instance, false alarms are assumed to occur when new items are not detected as new ($1 - P_r$) and at the same time are judged as being old (B_r). Parameter B_r can be calculated as follows: B_r = false alarms/[1 – P_r] = false alarms/[1 – (hits – false alarms)] (Equation 8 in Snodgrass and Corwin, 1988, p. 38).

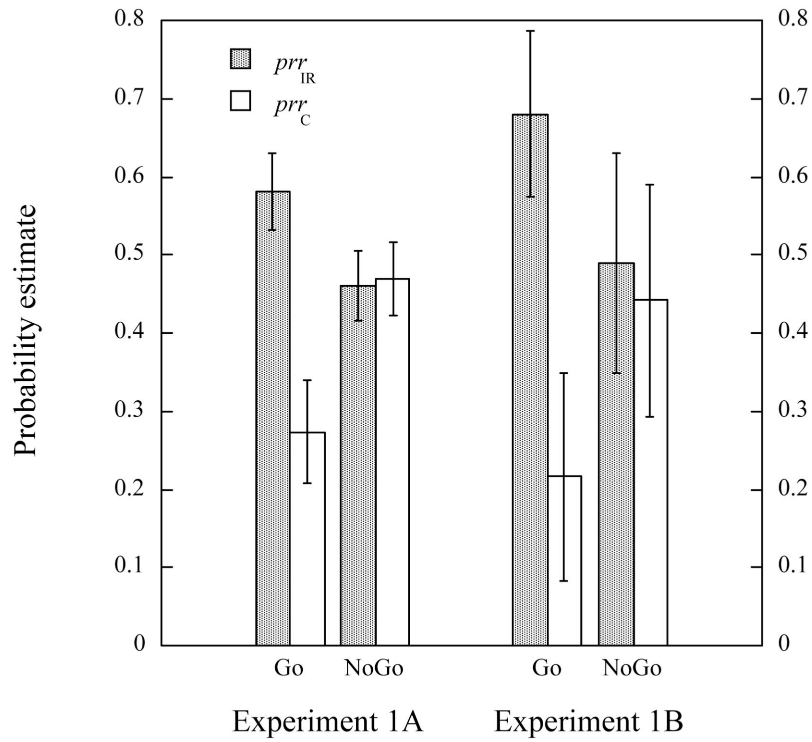

Figure 2. Probability estimates for the model parameters representing the probability of prime–response retrieval as a function of prime response and trial type for Experiments 1A and 1B. The error bars depict the 95% confidence intervals. prr_{IR} = probability of prime–response retrieval in the ignored repetition condition; prr_C = probability of prime–response retrieval in the control condition.

.01, $\eta^2 = .77$, and $t(116) = 18.22$, $p < .01$, $\eta^2 = .74$, for ignored repetition and control trials, respectively. The same was true for the no–go condition, $t(119) = 10.61$, $p < .01$, $\eta^2 = .48$, and $t(121) = 12.56$, $p < .01$, $\eta^2 = .56$, respectively.

The statistical analysis of the response bias index, B_r, revealed neither a main effect of prime response, $F(1, 97) = 0.87$, $p = .35$, $\eta^2 = .01$, nor a main effect of trial type, $F(1, 97) = 1.79$, $p = .19$, $\eta^2 = .02$, nor a significant interaction between the two variables, $F(1, 97) = 0.09$, $p = .77$, $\eta^2 < .01$.

Follow-up tests showed that the two trial type conditions did not differ from each other in the go condition, $t(107) = -1.51$, $p = .14$, $\eta^2 = .02$, and in the no–go condition, $t(115) = -1.12$, $p = .27$, $\eta^2 = .01$. Response bias was conservative for all conditions in that it was significantly smaller than .5, which marks the neutral value for B_r, $t(117) = -7.38$, $p < .01$, $\eta^2 = .78$, and $t(116) = -4.74$, $p < .01$, $\eta^2 = .75$, for ignored repetition and control trials in the go condition, and $t(119) = -6.74$, $p < .01$, $\eta^2 = .82$, and $t(121) = -4.43$, $p < .01$, $\eta^2 = .77$, for ignored repetition and control trials in the no–go condition, respectively. The conservative response bias was unsurprising given the base rate of .75 of trials with different test tones implying a *no* response as the correct answer.

Discussion

First, Experiment 1A yielded the pattern of results predicted by the prime–response retrieval model, that is, a prime–response retrieval effect in go trials but no prime–response retrieval effect in no–go trials. This can be counted as novel evidence in favor of the prime–response retrieval model of negative priming. Second, the negative priming effect was present (albeit reduced) in the overall reaction times in no–go trials. The overall error rates did not complicate the interpretation of this result. These results permit the assumption that prime–response retrieval is not the sole mechanism to induce negative priming.

Unfortunately, the clarity of results may be complicated by a possibly confounding variable, as the analysis of the control question suggests. Prime targets in the go condition were better remembered than prime targets in the no–go condition. This may be interpreted to indicate that prime presentations of go trials were better encoded than those of no–go trials. This could have been due to the fact that participants saw the visual task cue indicating whether or not they had to respond to the prime 400 ms before the auditory cue of the prime presentation. As a consequence participants did not allocate as much attention to the prime target in no–go trials as they did in go trials. This confounding in attentional allocation to the prime target stimulus with prime response requirement might be responsible for the difference in the size of the reaction time and overall error-negative priming effects but also for the difference between go and no–go trials in terms of the prime–response retrieval effect. In order to exclude this confounding as an explanation for the differential results in go and no–go trials, we ran Experiment 1B as a replication of Experiment 1A.

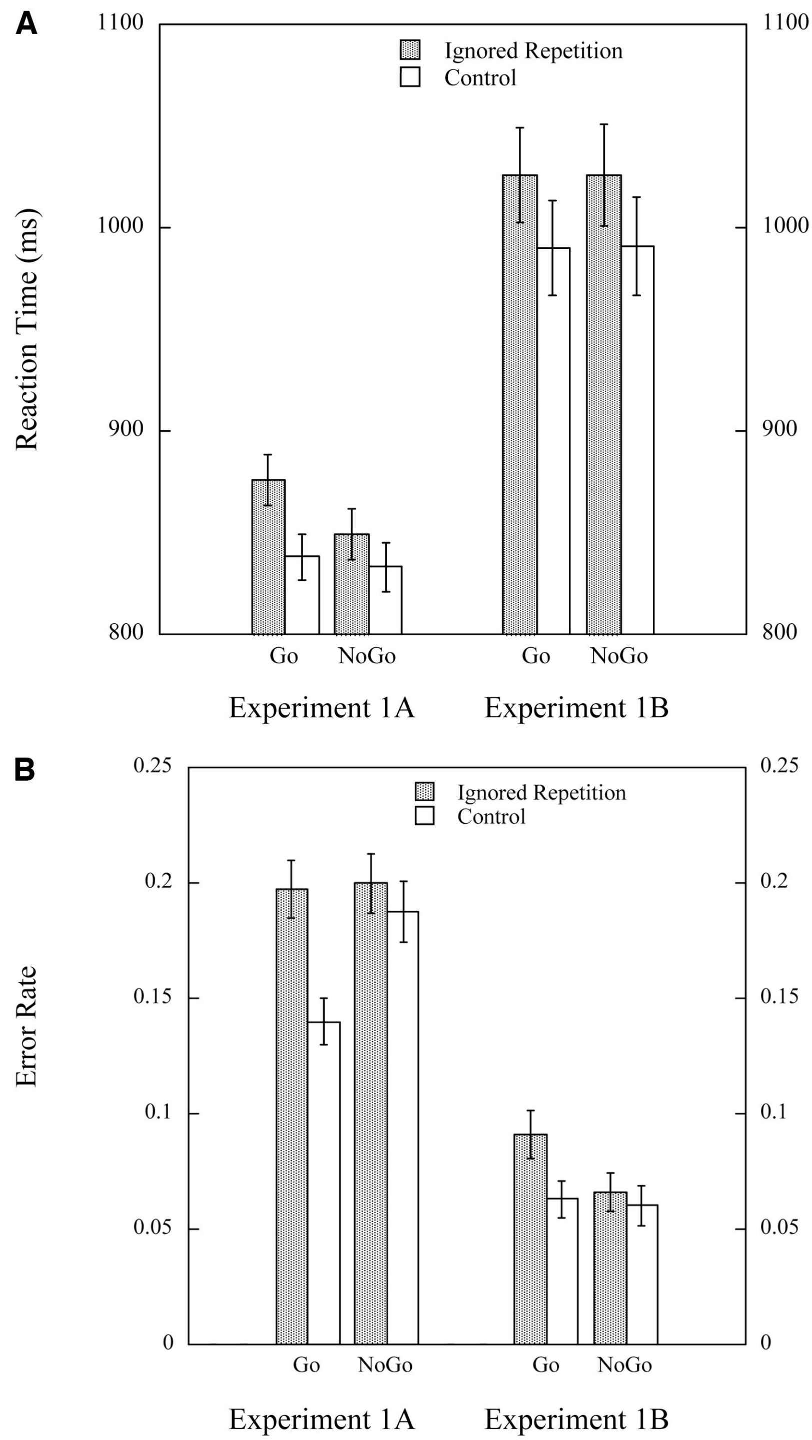

Figure 3. Reaction times (Panel A) and error rates (Panel B) as a function of prime response and trial type for Experiments 1A and 1B. The error bars depict the standard errors of the means.

Different from Experiment 1A, the visual task cue was presented after the prime presentation. At the time of the prime sound onset, participants did not know whether they would have to respond or not. Consequently, they should allocate their attention to the prime target to the same extent in go as in no–go trials. If our concerns with the possible confound in Experiment 1A were unfounded, then we should still find the prime–response retrieval effect in ignored repetition compared to control trials for the go condition but not for the no–go condition.

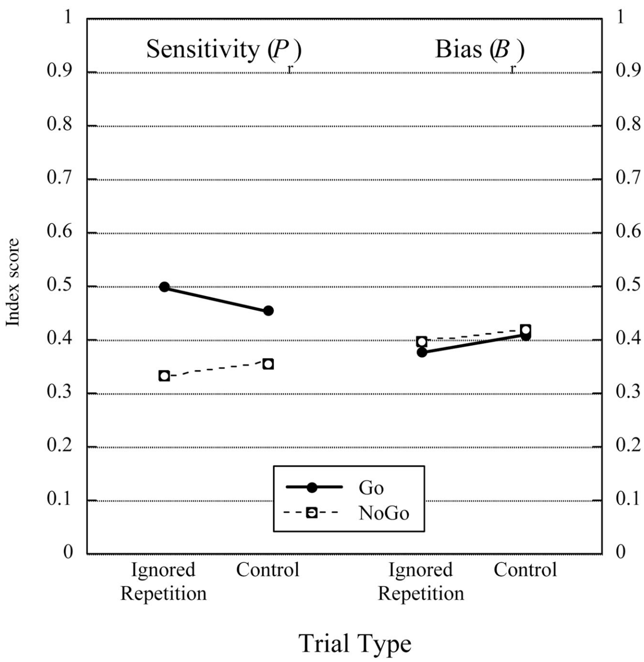

Figure 4. Sensitivity and response bias indexes as a function of prime response and trial type for the control question of Experiment 1A.

Experiment 1B

Method

Participants. Participants were 67 adults (mostly students), 39 women and 28 men. They ranged in age from 18 to 39 years (M = 25.87, SD = 5.59). Seven additional participants did not reach one of the two learning criteria of 75% correct reactions in the first training phase or of 60% correct reactions in the second training phase. Participants were paid €8.00 for their participation.

Materials. Materials were identical to those of Experiment 1A, with the following exceptions. Visual task cues indicating whether participants had to react (in the go condition) or to withhold a response (in the no–go condition) were presented 150 ms after stimulus presentation in the prime and in the probe. Additionally, the assignment of the fingers to the four sagitally aligned buttons of the response box was varied between participants. They were alternately instructed to press the two more distal buttons with the middle and index fingers of their right hand and the two more proximal buttons with the middle and index fingers of their left hand or vice versa.

Procedure. The procedure was the same as that of Experiment 1A with the exception that the control question was dropped due to the changes in visual task cue timing. Also, the training in Experiment 1B was slightly modified in that participants were exposed to 10 prime–probe pairs of trials after the first training of single trials and before they were introduced to the visual task cues. This was done in an attempt to reduce the dropout rate. Additionally, instructions stressed accuracy more than did those in Experiment 1A.

Each of the 384 experimental trials began with the presentation of the metronome click. After a 400-ms click–target interval, the prime pair of tones was presented. Then 150 ms later the visual task cue (i.e., the go or no–go sign) appeared. The visual task cue stayed on until the participant responded or until the prime time-out interval of 2,300 ms after prime tone onset was over. Then 2,500 ms after the prime tone onset, the probe click indicating the to-be-attended side in the probe was presented. Again, after a click–target interval of 400 ms the probe pair of tones was played. Another 150 ms after the probe pair of sounds, the visual probe cue (always the go signal) appeared. Participants had to respond within 3,000 ms after onset of the probe stimuli. Prime and probe responses within 250 ms after stimulus presentation—that is within 100 ms after the onset of the visual task cue—were counted as errors. After each prime–probe pair participants were given auditory and visual feedback about their performance. Too fast and too slow responses as well as responses in no–go prime presentations were followed by appropriate feedback.

After trial feedback, a 1,500-ms intertrial interval followed before the auditory cue of the next trial was presented. After every 20th trial, participants received a summary feedback about their average reaction time and error percentage within the last block.

Design. The design was the same as that of Experiment 1A. Again, we assumed w = 0.0415 as the population effect size for the comparison of the *prr* parameter between the ignored repetition and control condition. Assuming a contribution of approximately 80 utilizable probe responses per participant in the go as well as in the no–go condition (i.e., about 40 responses in each ignored repetition and control condition) and desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of at least N = 95 participants. We were able to collect data from N = 67 participants so that the power was actually somewhat smaller than what we had planned for ($1 - \beta \approx .90$).

To test whether the size of the negative priming effect in response times (and overall error rates) was influenced by the prime response variable, we examined the interaction between trial type and prime response. Given a population correlation of $\rho = .7$ between the difference variables of reaction times (ignored repetition vs. control) in the two levels of the prime response variable (or vice versa) and desired levels of $\alpha = \beta = .05$, a sensitivity analysis revealed that we were able to detect effects of size f = 0.17 (between small and medium effects as defined by Cohen, 1988). This corresponds to assuming $\eta^2 = .17$ as the population effect size.

Results

The frequency data for each response category are displayed in the lower half of Table 2. As with Experiment 1A, the multinomial model displayed in Figure 1 fit the frequency data of Experiment 1B perfectly. The parameter estimates of the critical retrieval process (prr_{IR} and prr_C) are illustrated for the two levels of the prime response variable in the right half of Figure 2. For the go as well as for the no–go condition, we tested the goodness-of-fit test of the model with the restriction that $prr_{IR} = prr_C$, which is implied by the nonresponse variant of the episodic retrieval account. The restricted model did not fit the data for the go condition, $G^2(1) = 22.28$, $p < .01$, $w = 0.0621$, and had to be rejected. However, the model could not be rejected for the no–go condition, $G^2(1) = 0.21$, $p = .65$, $w = 0.0058$.

Probe reactions were evaluated only for trials in which both the prime and the probe reactions were correct. The right half of Figure 3 (Panel A) shows that the mean reaction times (based on the individual mean reaction times) were higher in the ignored repetition than in the control condition, whereas the prime response manipulation did not influence reaction times.

A 2 $\times$ 2 MANOVA of the reaction time data with trial type (ignored repetition vs. control) and prime response (go vs. no–go) as within-subjects variables showed a significant main effect of trial type, $F(1, 66) = 21.12$, $p < .01$, $\eta^2 = .24$. Neither the main effect of prime response nor the interaction between trial type and prime response were significant, $F(1, 66) < 0.01$, $p = .97$, $\eta^2 < .01$, and $F(1, 66) = 0.03$, $p = .86$, $\eta^2 < .01$, respectively. Negative priming was significant at both levels of the prime response variable as is shown by follow-up tests; for the go condition, $t(66) = 3.54$, $p < .01$, $\eta^2 = .16$, and for the no–go condition, $t(66) = 4.42$, $p < .01$, $\eta^2 = .23$.

An analogous analysis of the error data (Panel B of Figure 3, right half) showed significant main effects of trial type, $F(1, 66) = 12.49$, $p < .01$, $\eta^2 = .16$, and of prime response, $F(1, 66) = 4.57$, $p = .04$, $\eta^2 = .07$. The interaction of trial type and prime response was also significant, $F(1, 66) = 4.46$, $p = .04$, $\eta^2 = .06$. Negative priming was significant for the go condition, $t(66) = 3.53$, $p < .01$, $\eta^2 = .16$, but not for the no–go condition, $t(66) = 0.91$, $p = .37$, $\eta^2 = .01$.

Discussion

As in Experiment 1A, we found a prime–response retrieval effect for go trials but not for no–go trials in Experiment 1B. Whereas the interpretation of this finding may have been considered ambiguous in Experiment 1A where prime presentations of the go condition may have received more attentional allocation than prime presentations of the no–go condition, the results of Experiment 1B leave no reason for skepticism: The go/no–go information was given after the onset of the prime stimuli, which necessarily implies equivalent processing of go and no–go primes, at least up to the point at which the go or no–go signal was given.

The analyses of reaction times revealed a significantly reduced negative priming effect in the no–go condition of Experiment 1A, whereas negative priming in Experiment 1B was independent of the prime response manipulation. In contrast to the reaction time results, negative priming in overall error rate was absent in no–go trials of both experiments. Bearing in mind that both experiments were not primarily designed to find differences in the size of the classical negative priming effect between go and no–go trials, the combined results suggest that the negative priming effect in error rates is crucially influenced by the prime–response retrieval mechanism, whereas the effect in reaction times—if anything—is only partially determined by prime–response retrieval.

Experiments 1A and 1B provide converging evidence for the retrieval of prime response information being involved in the processes that bring about the negative priming phenomenon. However, so far we do not know what aspect of the response encoded with the prime episode is responsible for the prime–response retrieval effect. Several aspects of the prime response could be crucial. A schematic sequence of processing stages that are supposed to take place during a typical prime presentation might help to illustrate these aspects (see Figure 5). Let us assume that a participant has to respond to the prime target stimulus *piano* with a button press of the right index finger. In Figure 5, the possible codes of this prime response are attached to successive processing stages.

One possibility is that the motor program executed for the right index finger might be encoded and stored in the prime episode and later on retrieved in the probe. Alternatively, the prime response could be encoded at an earlier processing stage, either at a premotor level in the form of a response preparation plan (i.e., "react with right index finger") or in the form of a response description in task-specific terms (i.e., "piano").

The results of Experiment 1A and 1B are compatible with prime–response retrieval at each of these three stages because we manipulated the response requirement at an early point in the prime processing—either before or directly after the prime presentation. Thus, we have to assume that participants did not generate or store a response at any of the three possible processing stages in the no–go trials.

We therefore conducted Experiment 2 to decide what type of prime response is retrieved in ignored repetition trials. Specifically, we tested whether retrieval of a motor response program takes place or whether the retrieved response has been encoded earlier, either in terms of a response preparation plan or at a task-specific response selection level.

Experiment 2

In Experiment 2, the go/no–go task of Experiment 1B was extended to a selective go/no–go task following the idea of a selective stop task based on motor discrimination as used by Verbruggen, Liefooghe, and Vandierendonck (2005, Experiment

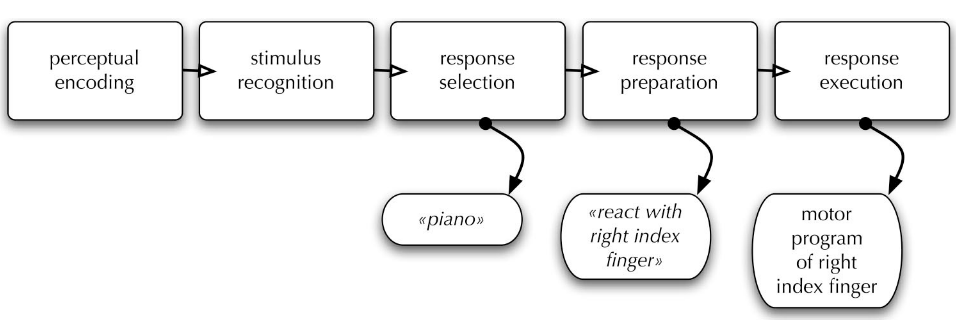

Figure 5. Sequential information processing model.

2) and reported by Logan (1994). As in Experiment 1B, participants saw either go or no–go cues after presentation of the prime stimuli. In contrast to Experiment 1B, no–go cues required participants to withhold all right-hand responses but to execute all left-hand responses (for half of the participants; for the other half this was reversed). Trials with no–go cues were called *invalid no–go trials* if the response had to be executed. Trials with no–go cues without a response requirement were called *valid no–go trials*. By introducing this motor discrimination rule, prime targets regardless of cue type had to be processed to the point of response preparation in order to decide whether the potential response had to be executed with the left or right hand. Consequently, the prime processing of go as well as of invalid and valid no–go trials included the generation of prime responses at the level of task-specific response selection ("piano" in Figure 5) and at the level of a response preparation plan ("react with right index finger" in Figure 5). For go as well as for invalid no–go trials the prime episode should also be represented by the motor program of the executed prime response. For valid no–go trials, in contrast, no motor response was required such that a motor program of the prime response should not have been developed.

With regard to the prime–response retrieval effect, we expected a relative increase in prime–response retrieval errors for ignored repetition trials of the go condition as in Experiments 1A and 1B. Likewise, we expected a prime–response retrieval effect for the invalid no–go condition. No matter what the critical prime response information is for prime–response retrieval to occur—either motor program, response preparation plan, or response selection at the task level—it should be encoded in the prime episode of an invalid no–go trial. For valid no–go trials, however, a prime–response retrieval effect should emerge only under certain assumptions: If prime–response retrieval necessitates the retrieval of a motor program of the prime response, we should not find an effect in valid no–go trials because no prime response has been executed. In contrast, if the response generation at an earlier level (such as in the form of a response preparation plan or in the form of the response selection at the task level) was sufficient for successful prime–response retrieval, a prime–response retrieval effect should also be present in valid no–go trials.

Method

Participants. Participants were 163 adults (mostly students), 109 women and 54 men. They ranged in age from 17 to 48 years (M = 24.82, SD = 5.67). An additional 13 participants did not reach one of the two learning criteria of 75% correct reactions in the first training phase or of 60% correct reactions in the second training phase. For 3 further participants at least one condition comprised less than 10 valid probe reactions, which was defined as the minimum for calculating reliable averages. Participants were paid €8.00 for their participation.

Materials. Materials were the same as in Experiment 1B, except that no–go primes could be either valid or invalid. For no–go prime presentations, a response-stop rule defined whether participants were to withhold the prime response (i.e., a valid no–go trial) or to commit a response despite the no–go signal (i.e., an invalid no–go trial). For the 81 participants with the left response-stop rule, prime responses in no–go trials had to be inhibited if the response was to be made with the left hand, whereas prime responses with the right hand had to be executed despite the no–go signal. For the 82 participants with the right response-stop rule, the assignment was reversed. The assignment of hands to response buttons (press the two more distal buttons with fingers of the right hand and the two more proximal buttons with fingers of the left hand or vice versa) was counterbalanced between the groups with left and right response-stop rules.

Procedure. The procedure was almost identical to that of Experiment 1B. However, the task was more difficult than in Experiment 1B because participants additionally had to learn the response-stop rule. In order to facilitate the task, the tone–response association was presented in the upper left corner of the display throughout the whole experiment and not only at the beginning of the training phase.

After successfully passing the first training phase and the 10 prime–probe trials, participants were introduced to the go and no–go cues as well as to the response-stop rule. Participants were instructed either to inhibit responses of no–go trials when the response was to be made with fingers of the left hand and to respond despite no–go cues when the response was to be made with the right hand (left response-stop rule) or vice versa (right response-stop rule).

Of the 288 experimental prime–probe trials, 96 were go trials, 96 were valid no–go trials, and 96 were invalid no–go trials. As in Experiment 1B, the probes were always presentations with a go signal. Each of the 288 experimental trials began with the presentation of the metronome click. A 400-ms click–target interval followed, and then the prime pair of tones was presented. Then 150 ms later the visual task cue appeared. The visual task cue stayed on until the participant responded or until the prime time-out interval of 2,300 ms after prime tone onset was over. Then 2,500 ms after the prime tone onset, the probe click indicating the to-be-attended side in the probe was presented. After a click–target interval of 400 ms the probe pair of tones was played. Another 150 ms after the probe pair of sounds, the visual probe cue (always the go signal) appeared. Participants had to respond within 3,000 ms after onset of the probe stimuli. Prime and probe responses within 250 ms after stimulus presentation—that is, 100 ms after the onset of the visual task cue—were counted as errors. After each prime–probe pair participants were given auditory and visual feedback about their performance. Too fast and too slow responses, as well as responses in valid no–go prime presentations and no responses in invalid no–go prime presentations, were followed by appropriate feedback. After trial feedback, a 1,500-ms intertrial interval followed before the auditory cue of the next trial was presented.

Design. The experiment comprised a two-factor design with trial type (ignored repetition vs. control) and prime response (go vs. invalid no–go vs. valid no–go) as within-subjects variables. Dependent variables were the same as in the previous experiments.

As in Experiments 1A and 1B, we assumed a population effect size of w = 0.0415 for the comparison of the prr parameter between the ignored repetition and control conditions. Assuming a contribution of approximately 40 utilizable probe responses per participant in the go as well as in the invalid and valid no–go conditions (i.e., about 20 responses in each ignored repetition and control condition) and desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of N = 189 participants. We were able to collect data from N = 163 participants, so that the power was marginally smaller than what we had planned for ($1 - \beta \approx .94$).

To test whether the size of the negative priming effect in response times (and overall error rates) was influenced by the prime response variable, we examined the interaction between trial type and prime response. Given a population correlation of $\rho = .7$ between the difference variables of reaction times (ignored repetition vs. control) in the three levels of the prime response variable (or vice versa) and desired levels of $\alpha = \beta = .05$, a sensitivity analysis revealed that we were able to detect effects of size $f = 0.10$ (small effects as defined by Cohen, 1988). This corresponds to assuming $\eta^2 = .09$ as the population effect size.

Results

The frequency data for each response category are displayed in Table 3. As with Experiments 1A and 1B, the multinomial model displayed in Figure 1 fit the frequency data of Experiment 2 perfectly. The parameter estimates of the critical retrieval process (prr_{IR} and prr_C) are illustrated for the two levels of the prime response variable in Figure 6. For the go, the invalid no–go, as well as for the valid no–go conditions, we performed a goodness-of-fit test for the model with the restriction that $prr_{IR} = prr_C$. The restricted model did not fit the data for the go condition, $G^2(1) = 15.60$, $p < .01$, $w = 0.0462$, or the invalid no–go condition, $G^2(1) = 4.13$, $p = .04$, $w = 0.0238$. However, the model could not be rejected for the valid no–go condition, $G^2(1) = 0.28$, $p = .60$, $w = 0.0063$.

Probe reactions were evaluated only for trials in which both the prime and the probe reactions were correct. Figure 7 (Panel A) shows that the mean reaction times (based on the individual mean reaction times) were higher in the ignored repetition than in the control condition, whereas the prime response manipulation did not influence reaction times.

A 2 × 3 MANOVA of the reaction time data with trial type (ignored repetition vs. control) and prime response (go vs. invalid no–go vs. valid no–go) as within-subjects variables revealed significant main effects of trial type, $F(1, 162) = 36.86$, $p < .01$, $\eta^2 = .19$, and of prime response, $F(2, 161) = 4.48$, $p = .01$, $\eta^2 = .05$. The interaction between trial type and prime response was not significant, $F(2, 161) = 1.38$, $p = .97$, $\eta^2 = .02$. Negative priming was significant at all three levels of the prime response variable as is shown by follow-up tests; for the go condition, $t(162) = 4.43$, $p < .01$, $\eta^2 = .11$; for the invalid no–go condition, $t(162) = 5.35$, $p < .01$, $\eta^2 = .15$; and for the valid no–go condition, $t(162) = 2.94$, $p < .01$, $\eta^2 = .05$.

An analogous analysis of the error data (Panel B of Figure 7) showed a significant main effect of trial type, $F(1, 162) = 22.32$, $p < .01$, $\eta^2 = .12$. Neither the main effect of prime response nor the interaction between trial type and prime response were significant, $F(2, 161) = 1.18$, $p = .31$, $\eta^2 = .01$, and $F(2, 161) = 0.38$, $p = .69$, $\eta^2 < .01$, respectively. Negative priming was significant at all three levels of the prime response variable as is shown by follow-up tests; for the go condition, $t(162) = 2.72$, $p < .01$, $\eta^2 = .04$; for the invalid no–go condition, $t(162) = 3.47$, $p < .01$, $\eta^2 = .07$; and for the valid no–go condition, $t(162) = 2.82$, $p < .01$, $\eta^2 = .05$.

Discussion

Experiment 2 was conducted to test in more detail which aspect of the retrieved prime response may be responsible for the prime–response retrieval effect. Using a selective go/no–go task based on motor discrimination, we implemented go and invalid no–go trials in which the retrieved prime episode should include a prime response representation in terms of a motor response program as well as in terms of a response preparation plan and a task-specific description. In contrast, the retrieved prime episodes of valid no–go trials should have contained only a response preparation plan and a response description in task-specific terms. For these trials a motor program of the prime response should not have been encoded and stored, given that no motor response was executed.

As expected, we found an increase in prime–response retrieval for ignored repetition trials of the go and the invalid no–go conditions. For valid no–go trials, however, the prime–response retrieval effect disappeared. Obviously, prime–response retrieval necessitates the retrieval of a motor program of the prime response, which was not the case for valid no–go trials.

Negative priming effects were found for all prime response conditions, both for reaction times and overall error rates. In contrast to the findings of Experiments 1A and 1B, the negative priming effects were of comparable size for all three prime response conditions.

Table 3
Accumulated Absolute Frequencies of Correct Probe Responses and of the Different Types of Probe Errors for the Ignored Repetition Condition and the Control Condition in Experiment 2

	Experiment 2					
	Go		Invalid no–go		Valid no–go	
Response	Ignored repetition	Control	Ignored repetition	Control	Ignored repetition	Control
Correct probe target responses	3,390	3,450	3,353	3,417	3,304	3,341
Incorrect probe distractor responses	194	168	229	182	200	150
Incorrect prime target responses	50	8	31	5	22	20
Other incorrect responses[a]	18	19	33	16	21	15

[a] In ignored repetition trials, this response category comprised responses with the key that was assigned to the nonpresented stimulus. In control trials, this response category comprised responses with the key that was assigned to the prime distractor stimulus.

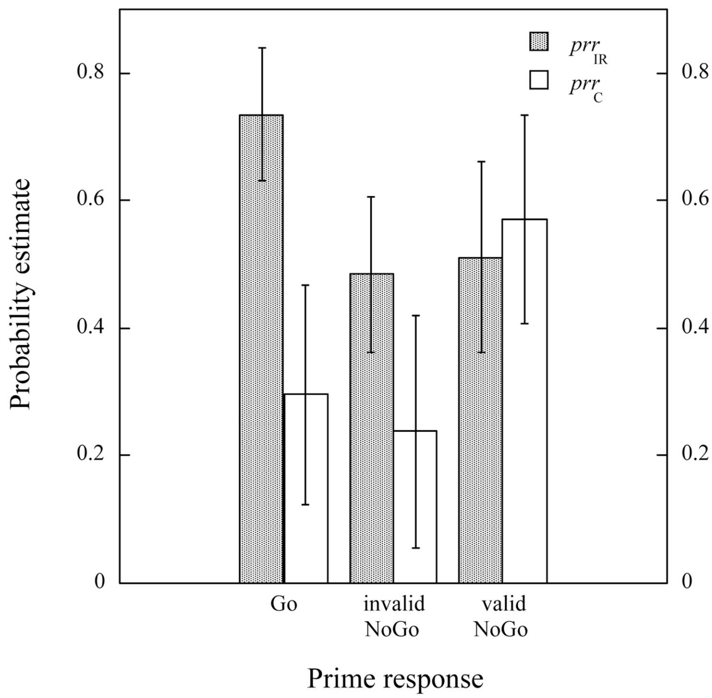

Figure 6. Probability estimates for the model parameters representing the probability of prime–response retrieval as a function of prime response and trial type for Experiment 2. The error bars depict the 95% confidence intervals. prr_{IR} = probability of prime–response retrieval in the ignored repetition condition; prr_C = probability of prime–response retrieval in the control condition.

General Discussion

The goal of the research reported here was to test, to extend, and to specify the prime–response retrieval account of negative priming. This variant of the episodic retrieval model postulates that the prime response is retrieved in the probes of ignored repetition trials and causes a task-inappropriate and time-consuming conflict. In three experiments we manipulated the prime response requirement in that participants were to respond to prime presentations accompanied by a go signal, whereas they were to refrain from responding in no–go trials. For go as well as for no–go trials, we found negative priming-specific slowed-down responding in ignored repetition trials compared to control trials. However, the prime–response retrieval effect—that is, the increase in prime response errors to probe presentations of ignored repetitions trials compared to control trials—was found only for go trials. In no–go trials, the prime–response retrieval effect disappeared in all three experiments. This result is perfectly compatible with the prime–response retrieval account: Retrieval of a prime response is possible only if a prime response has taken place (go trials). Without a prime response (no–go trials), no prime response can be retrieved. No other account of the negative priming phenomenon can explain this result. The original episodic retrieval model (Neill & Valdes, 1992; Neill et al., 1992) postulates that negative priming is caused by the probe-triggered retrieval of nonresponse information attached to the former prime distractor. The former prime response is of no relevance for this model. Therefore, the model cannot explain both the increase of prime response errors in ignored repetition trials of go trials and the absence of this increase for no–go trials. Similarly, the distractor inhibition model (Houghton & Tipper, 1994; Tipper, 1985, 2001; Tipper & Cranston, 1985) also ignores the role of the former prime response by postulating a forward-acting suppression mechanism to act upon the to-be-ignored distractor representations and/or a blocking of the translation into a response code. Thus, this model also cannot account for the present go/no–go difference in the prime–response retrieval effect.

Note, however, that the go/no–go difference in the prime–response retrieval effect does not imply that prime–response retrieval is the sole mechanism to induce negative priming—quite to the contrary, the negative priming effects in reaction times and overall errors we found with no–go trials refute this implication (see below). It is probably more adequate to think of a unitary retrieval process and of prime–response information as well as nonresponse information as two aspects of the prime episode that can be retrieved, among others. Whether both aspects or only one of them are retrieved depends partly on whether these aspects had been encoded and stored in the prime episode. This is compatible with the more general explanatory principle of transfer appropriate/inappropriate processing (Neill & Mathis, 1998). From the point of view of such a general explanatory principle, the retrieval of multiple incompatible pieces of information—such as prime response and nonresponse information—would increase the degree of transfer-inappropriate processing. Conceivably, retrieval of both incompatible prime–response and nonresponse information contributes to negative priming in go trials, whereas retrieval of just the nonresponse component is involved in causing negative prim-

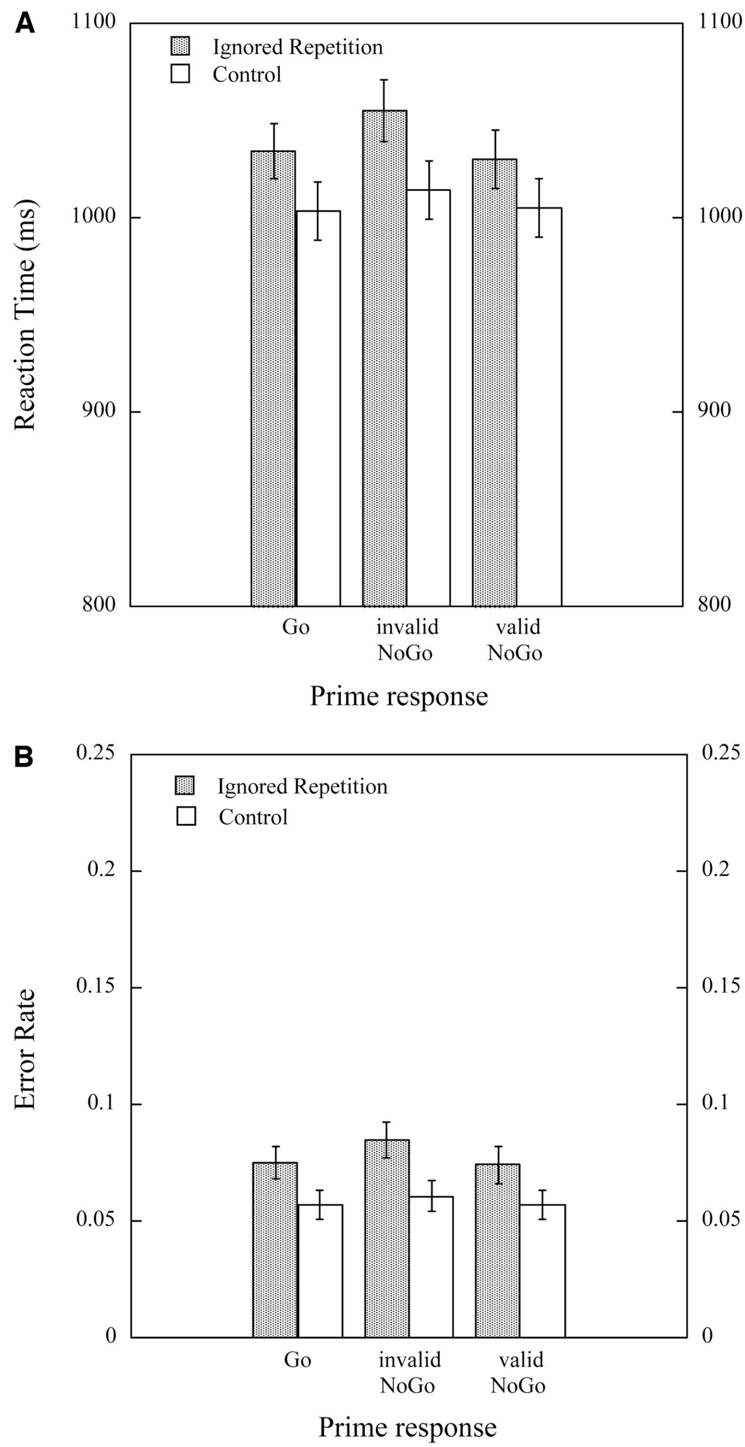

Figure 7. Reaction times (Panel A) and error rates (Panel B) as a function of prime response and trial type for Experiment 2. The error bars depict the standard errors of the means.

ing in no–go trials. Whether other processes (such as inhibition) are additionally involved in causing negative priming cannot be determined on the basis of our experiments.

Experiment 2 revealed important aspects of the prime–response retrieval mechanism and made it possible to specify more closely the processes involved. This experiment was planned to test whether the prime–response retrieval effect in ignored repetition trials is due to (a) the retrieval of a motor response (such as the motor program of the right index finger), (b) a response preparation plan (such as the plan to "react with right index finger"), or (c) a response specified at the task level (such as "piano"). Using a selective go/no–go task based on motor discrimination, we varied whether a motor response was generated and thus could be encoded in the prime episode (go and invalid no–go trials that required a prime response) or whether only a response preparation plan and a response description in task-specific terms could be encoded (valid no–go trials that required participants to withhold a response). We found a prime–response retrieval effect in the go and in the invalid no–go conditions in which retrieving a motor prime response was possible, whereas no evidence of prime–response retrieval was found in the valid no–go condition. We therefore conclude that retrieval of a motor response is essential for prime–response retrieval to occur, whereas the retrieval of a response preparation plan or of a response description in task-specific terms is not sufficient.

In terms of effect sizes, the prime–response retrieval effect was larger in the go than in the invalid no–go condition. This can be easily explained when we keep in mind that successful retrieval of prime episodes follows the same principles as memory retrieval processes do in general. Importantly, the context similarity of prime (i.e., encoding) and probe (i.e., retrieval) presentations was larger for go than for invalid no–go trials. First, prime and probe presentations of go trials included green task cues, whereas prime and probe presentations of invalid no–go trials were accompanied by red and green task cues, respectively. Second, the task in no–go trials varied from prime to probe in that the red prime task cue triggered a decision process as to whether to respond in the prime or not, whereas the green probe task cue uniquely specified one single response requirement. For go trials, however, there was no such difference between primes and probes. In essence, then, the context similarity between prime and probe was smaller for invalid no–go than for go trials. Therefore, the probability of successful prime–response retrieval must necessarily be smaller in the invalid no–go than in the go condition.

In addition to the prime–response retrieval effects, we also analyzed the "classical" negative priming effects in terms of response times and overall errors. The results of these analyses were very clear in showing that prime–response retrieval certainly cannot be the only mechanism involved in the negative priming phenomenon. In all three experiments, negative priming was found not only in go trials but also in no–go trials in which we found no evidence of prime–response retrieval. This result actually fits with a number of rather heterogeneous studies that have implemented prime conditions without response requirements (e.g., Healy & Burt, 2003; Milliken & Joordens, 1996; Mondor, Leboe, & Leboe, 2005). Unfortunately, although there are quite a few studies in which negative priming without prime response was measured (for a review, see Mayr & Buchner, 2007), we are aware of only one study in which the prime response requirement was manipulated in a way that is similar to the manipulation used here (Verbruggen et al., 2005). The similarity is not surprising because in their Experiment 2, Verbruggen et al. (2005) used a selective stop signal that we adapted for our Experiment 2. After the stop signal, participants had to withhold a response when the response would have been an index finger button press, whereas they had to respond when the response was to be conducted with the middle finger. Negative priming in terms of reaction times was observed even after successfully withholding a prime response, just like in the valid no–go condition of the present Experiment 2. However, there is a difference in the findings between Experiment 1 of Verbruggen et al. and the present Experiments 1A and 1B. This difference is puzzling at first, but it seems as if there is a simple explanation. In contrast to our experiments, Verbruggen et al. implemented a procedure in which the delay of the stop signal was individually adapted to guarantee a successful stopping in about 50% of the trials. Negative priming was always found when a response had been executed in the prime (i.e., both in trials without a stop signal in the prime and in trials with a stop signal but for which the inhibition of the prime response had failed). In contrast, the negative priming effect disappeared when the prime response was successfully withheld. This is at odds with our findings of Experiments 1A and 1B that showed negative priming in no–go trials, albeit reduced. It appears that the easiest and most likely explanation for the discrepancy in findings is revealed when one looks at the procedural details. In the Verbruggen et al. study the prime–probe stimulus contingencies were not balanced. More precisely, 50% of the trials in their four-alternative identification task were ignored repetition trials. This is twice as much as the base rate (25%). Participants most likely detected the frequent repetitions of prime distractors as probe targets. It is known that participants use this knowledge strategically in order to prepare for probe responding; as a consequence, slowed-down responding in ignored repetition trials may be reduced, absent, or even inverted into response facilitation (Frings & Wentura, 2006). Verbruggen et al.'s finding of a negative priming effect for normal trials without a stop signal and for stop signal trials with failed response inhibition does not contradict these considerations. First, for normal trials without a stop signal, the strategic effect probably reduced but did not eliminate the inherently larger (compared to stop signal trials) negative priming effect. Second, failed stop signal trials usually release a number of error evaluation processes that might annihilate the strategic component of processing the upcoming probe trial.

Given this explanation of the Verbruggen et al. (2005) data, the present experiments clarify that negative priming in terms of probe response speed is found regardless of whether the prime requires a response or not and irrespective of whether a selective or a general stop signal indicates prime response requirements. This means that although prime–response motor program retrieval is involved in negative priming, it can be only one of several mechanisms contributing to the effect.

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