

The time-course of negative priming: Little evidence for episodic trace retrieval

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An episodic trace retrieval (ETR) explanation of negative priming (NP) predicts that the NP effect should be sensitive to the timing of delays between trials (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). Specifically, according to ETR, (1) NP is affected by the response-stimulus interval (RSI) before the prime display, and (2) NP decays when RSI is manipulated within groups but not when RSI is manipulated between groups. Two localization tasks and two identification tasks are reported that question the reliability of these findings. The results suggest that there is little in the time-course literature that uniquely supports the ETR theory of NP. Instead, the results seem more compatible with either a dual-mechanism account (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997) or an integrative approach that incorporates both memory and attention processes (Milliken, Joordens, Merikle, & Seiffert, 1998).

Negative priming (NP) refers to the finding that responses are slowed to stimuli that have recently been ignored or selected against (Dalrymple-Alford & Budayr, 1966; Tipper, 1985). Tasks designed to observe NP have been used to investigate the processes involved in selective attention, under the assumption that NP reflects the action, and so the existence of, an inhibitory mechanism (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995). However, an alternative account of NP, the episodic trace retrieval (ETR) theory, has been proposed and can account for a majority of NP effects that have been reported over the last two decades. The ETR theory was first proposed because it could account for a complex set of findings with respect to the time-course of NP (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). However, some of these findings may be suspect. Therefore, the purpose of this paper is to reexamine the time-course effects presented as evidence in support of ETR. My goal is not to completely reject ETR as an explanation of NP—because not enough evidence has been reported to clearly reject ETR theory—or to reject an inhibition-based theory, a dual-mechanism account (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997), or an integrative approach that incorporates both memory and attention processes (Milliken, Joor-

dens, Merikle, & Seiffert, 1998). Instead, I will reevaluate the time-course literature and present four new experiments, to illustrate that there is, in fact, little evidence in the time-course literature to support ETR.

According to inhibition-based accounts of NP (Allport, Tipper, & Chmiel, 1985; Fox, 1995; Greenwald, 1972; Houghton & Tipper, 1994; Milliken, Tipper, & Weaver, 1994; Moore, 1994; Neill, 1977; Neill & Westberry, 1987; Neumann & DeSchepper, 1991, 1992; Tipper, 1985; Tipper & Cranston, 1985; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991; Yee, 1991), both the target and the distractor are processed in parallel. The memory representation of the target competes with the memory representation of the distractor for access to a response mechanism. As part of this competition, the link between the representation of the distractor and the response mechanism is inhibited. Thus, on a distractor-target trial, the subject is slowed to respond to the probe target because the link between the representation pertaining to the target and the response mechanism was previously inhibited on the prime display.

The ETR theory of NP assumes no inhibitory mechanism. According to the theory, prime distractor information is tagged in memory as a unique episodic trace. For example, in a letter-naming task, if the subject is presented with a red B and a green D, he or she will respond by naming the red B and will also form a memory trace of the distractor that takes the form *green-D—do not respond*. Thus, on the subsequent trial, if the subject is presented with a red D, he or she will automatically retrieve the prime information (*green-D—do not respond*), which will conflict with the appropriate response, which will cause slowing.

It is possible that both inhibition and ETR contribute to the NP effect. Kane et al. (1997) proposed a *dual-mechanism* account of NP, in which certain task characteristics either encourage or discourage ETR. For instance, if the physical features of the probe display are distorted, subjects may rely on the retrieval of prime information to help identify the probe, which would encourage ETR.

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Finally, a recent account of NP does not assume either ETR or inhibition, although it does incorporate both memory and attention processes. Milliken et al. (1998) refer to their theory as a *temporal discrimination* account, in which "negative priming is an emergent consequence of a discrimination process that is inherent to memory retrieval. Importantly, this discrimination process has an attentional basis" (p. 210). According to the theory, stimuli are categorized as either *new* or *old*. Stimuli are responded to most quickly if they can be quickly categorized as new or old, whereas processing is slowed if there is ambiguity. Negative priming paradigms provide ambiguity, because the probe target is categorized by an orienting/attention mechanism as new, but, since it is related to the prime distractor, it is categorized by a retrieval mechanism as old, which leads to confusion, which leads to slowing.

In an attempt to streamline this introduction, only ETR theory and its account of time-course effects will be discussed in detail. I will return to the more recent accounts of NP in the discussion.

The ETR theory was developed to account for seemingly discrepant data regarding the time-course of NP. Neill and Westberry (1987) and Neill and Valdes (1992) reported that NP dissipates quickly, on the order of 1 or 2 sec. In contrast, Tipper et al. (1991) and Hasher, Stoltzfus, Zacks, and Rypma (1991) found that NP was consistent for up to 7 or 8 sec.

Why did Neill and Westberry (1987) and Neill and Valdes (1992) find a decline in NP, whereas Tipper et al. (1991) and Hasher et al. (1991) did not? Neill and Valdes argued that the discrepancy was due to different experimental designs. When RSI was manipulated within groups (Neill & Valdes, 1992; Neill & Westberry, 1987), the NP effect declined over RSI, but when RSI was manipulated between groups (Hasher et al., 1991; Tipper et al., 1991), the NP effect was stable over RSI.

According to ETR, the probability of retrieving an episodic trace is dependent on trace strength and trace discrimination. Neill and Valdes (1992) argued that the RSI manipulation affects trace discrimination. When RSI is manipulated between groups, the temporal interval between the prime display and the probe display is the same as the temporal interval between the prime display and the preceding display, and it is the same as the temporal interval between each and every display in the experiment. Thus, the ratio of the interval between the prime and the probe to the interval between all other displays in the experiment is 1:1.

Consider what happens when RSI is manipulated within groups. If the interval between the prime and the probe is long, the ratio of the interval between the prime and the probe to the interval between all other displays in the experiment will not be 1:1. The interval between the prime and the probe will be longer, on average, than the rest of the intervals, meaning that there will be a larger temporal gap between the prime and the probe display than be-

tween the prime display and the previous probe. This will cause trace discrimination of prime information to be poor, which will lead to a lower probability of retrieval, which will lead to a smaller NP effect. If the interval between the prime and the probe is short, the interval between the prime and the probe will be shorter, on average, than the rest of the intervals in the experiment, leading to better trace discrimination, which will lead to a higher probability of retrieving the prime information, which will lead to a larger NP effect.

An interesting prediction of the ETR theory is that the NP effect depends not only on the RSI between the prime and the probe, but also on the RSI between the prime and the previous display. I will refer to this earlier RSI as the previous RSI (PRSI). Neill et al. (1992) tested this prediction. They had subjects perform a localization task and manipulated RSI with intervals of either 500 or 4,000 msec. If we consider PRSI and RSI together, there are four possible combinations: 500–500, 500–4,000, 4,000–500, and 4,000–4,000. ETR theory predicts that the largest NP will occur with a PRSI–RSI combination of 4,000–500 msec, because the ratio of the prime–probe interval to the prime–previous-display interval is 500:4,000, or 1:8. Thus, the temporal relationship between the prime and the probe, relative to the temporal relationship between the prime and the previous display, is small, meaning that the prime display is highly discriminable.

Now consider the PRSI–RSI combination of 500–4,000 msec. Here, the ratio of the prime–probe interval to the prime–previous-display interval is 4,000:500, or 8:1. Thus, the gap between the prime and the probe, relative to the gap between the prime and the previous display, is large, which will cause the prime display to be less discriminable, which will lead to reduced NP.

For the other two PRSI–RSI combinations, 500–500 msec and 4,000–4,000 msec, the ratio of the prime–probe interval to the prime–previous-display interval is 1:1. Thus, ETR theory predicts equivalent NP in these two conditions. Furthermore, the theory predicts that the NP effect in these two conditions will be smaller than that in the 4,000–500 msec condition and larger than that in the 500–4,000 msec condition.

The results of Neill et al. (1992) fit perfectly with the ETR predictions. In the 500–500 msec and 4,000–4,000 msec conditions, they found NP of 26 and 20 msec, respectively, and these effect sizes were not statistically different. There was an NP effect of 39 msec in the 4,000–500 msec condition, and there was an NP effect of 14 msec in the 500–4,000 msec condition. Thus, the results of Neill and Valdes (1992) and Neill et al. have been taken as support for ETR and are cited as raising problems for inhibition accounts of NP (Fox, 1995; May et al., 1995).

To summarize, there are two findings from the time-course literature that provide support for ETR. They are (1) the finding that the NP effect depends on the RSI before the prime display (the PRSI) and (2) the fact that the NP effect has been found to decay over time when RSI is

manipulated within groups, but not when RSI is manipulated between groups. In the subsequent section, I will argue that both of these findings are suspect.

The first finding mentioned above is that the NP effect depends on the RSI before the prime display (the PRSI). This finding has been reported in only one experiment (Neill et al., 1992, Experiment 1), and in fact, the appropriate statistical test was not reported. The appropriate test is to examine the PRSI \times trial type interaction, because ETR theory predicts that NP depends on PRSI, so that NP effects are larger following a long PRSI than following a short PRSI. Unfortunately, the test of this interaction was not reported by Neill et al. (1992).

The second finding mentioned above is that NP appears to decay when RSI is manipulated within groups, but not when RSI is manipulated between groups. This finding has recently been challenged by Hasher, Zacks, Stoltzfus, Kane, and Connelly (1996), who conducted two experiments to test the reliability of the findings reported by Neill et al. (1992). Both experiments were localization tasks, exactly like the task used by Neill et al. Also, in both experiments, RSI was manipulated randomly within groups. However, instead of using 500- and 4,000-msec RSIs, they used 500- and 2,500-msec RSIs. Hasher et al. (1996) failed to detect a decay of NP in both experiments. Thus, there is now evidence that NP does not decay even when RSI is manipulated randomly within groups.

There are, however, two concerns about the Hasher et al. (1996) paper. One potential problem is that their RSI manipulation was not powerful enough, because the long RSI was 2,500 msec, as opposed to the 4,000-msec RSI in Neill et al. (1992). The second concern is that, in their Experiment 2, they found slight trends that, although not significant, would favor ETR theory. They found slightly greater NP after a 500-msec RSI (16 msec) than after a 2,500-msec RSI (12 msec). Also, when response times were broken down by PRSI-RSI combination, the NP effect was slightly larger in the 2,500-500 msec condition (17 msec) than in the 500-2,500 msec condition (10 msec). Thus, these slight trends may suggest that evidence for ETR theory would have emerged if they had incorporated the longer, 4,000-msec RSI.

Four experiments were conducted in order to evaluate the time-course of NP. Experiment 1 used a localization task, like the one reported by Neill et al. (1992). RSI was manipulated randomly within groups, with intervals of 500 and 4,000 msec. ETR theory predicts an interaction between trial type and PRSI in such a way that the NP effect would be larger following a 4,000-msec PRSI than following a 500-msec PRSI. Also, because RSI is manipulated within groups, ETR predicts a decay of NP, which would be illustrated by an interaction between trial type and RSI, in such a way that the NP effect following a 500-msec RSI would be larger than that following a 4,000-msec RSI.

The manipulation in Experiment 2 provides a more direct comparison with respect to detecting the interaction between trial type and PRSI. In Experiment 1 of Neill et al. (1992), both experiments of Hasher et al. (1996), and the present Experiment 1, there were two

levels of RSI and two levels of PRSI. Thus, there were four PRSI-RSI combinations. According to ETR theory, the largest NP effect should be observed when the PRSI is long and the RSI is short. In contrast, the smallest amount of NP should be observed when the PRSI is short and the RSI is long. Therefore, in Experiment 2, only two of the four PRSI-RSI combinations were used: 4,000-500 and 500-4,000. This manipulation allows a direct comparison of the two time conditions that should result in the largest difference in NP.

Another difference between Experiment 1 and Experiment 2 is the predictability of RSI. In Experiment 1, RSI was manipulated randomly, so that the subject could not predict the timing of each upcoming trial. In Experiment 2, RSI consistently alternated from 500 msec to 4,000 msec, and therefore, the subject was able to predict the timing of each upcoming trial. According to ETR theory, NP should not be affected by predictability, because priming is caused by the automatic retrieval of conflicting prime information (Neill & Valdes, 1992). Thus, the magnitude of the NP effect should be equivalent in Experiments 1 and 2.

According to an inhibitory account, the process of suppressing irrelevant information is a controlled, effortful process (Conway, Tuholski, Shisler, & Engle, in press; Engle, Conway, Tuholski, & Shisler, 1995; Nakagawa, 1991; Neumann & DeSchepper, 1992; Roberts, Hager, & Heron, 1994). For example, Engle et al. had subjects perform an NP task while concurrently maintaining a secondary memory load. As the secondary memory load increased, the NP effect decreased, suggesting that inhibition, as measured by NP, is resource demanding. When the events of a task are predictable, the subject should be able to exert more attentional control than when the events are unpredictable. Therefore, inhibition theory would predict a larger NP effect when RSI is consistent than when RSI is random.

Experiments 3 and 4 were conducted with the hope that the results of Experiments 1 and 2 could be generalized to an identification task. Therefore, in Experiments 3 and 4, the subject was presented with a red and a green letter and instructed to respond to the identity of the red letter. The RSI manipulations were exactly the same as those in Experiments 1 and 2.

EXPERIMENT 1

Method

Subjects. Forty-five undergraduates from the Georgia Institute of Technology participated in exchange for course credit.

Stimuli and Apparatus. Stimuli were presented on a CTX color monitor controlled by a Dell Pentium computer. The experimental programs were controlled by MEL software.

On each trial, four equal signs (=) appeared as location markers on the 11th print line of the monitor screen, centered and separated by three blank spaces. A plus sign (+) served as a fixation point and warning signal and was presented at the center of the 10th print line. A target O and distractor X then appeared on the 10th print line, each above one of the four location markers.

Procedure. The subjects were instructed to respond to the location of a target O while ignoring the location of a distractor X. They responded by pressing a key, corresponding to the location of the

Table 1
Reaction Times (With Standard Deviations) for Prime or Probe Display as a
Function of Trial Type and PRSI, RSI, and PRSI-RSI in Milliseconds: Experiment 1

	Trial Type						Interference	Priming
	Distractor-Target		Control		No Selection			
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
	Prime Display							
PRSI								
500	422	50	422	49	400	47	22	
4,000	418	49	422	51	398	44	24	
	Probe Display							
RSI								
500	425	46	416	51	414	49	-9	
4,000	426	54	413	45	415	46	-13	
	Probe Display							
PRSI-RSI								
500/500	425	50	417	53	416	50	-8	
500/4,000	423	53	417	45	416	47	-6	
4,000/500	426	45	416	50	413	50	-10	
4,000/4,000	430	58	413	46	417	54	-17	

target, on the computer keyboard. Responses were made on the S, C, L, and M keys. The subjects were instructed to keep one finger on each key throughout the experimental session. Specifically, they used the middle and index fingers of each hand to respond. The locations of the target and the distractor were counterbalanced, so that each of the four locations was used equally.

Each subject performed 12 blocks of 50 trials. Each trial consisted of a prime display and a probe display. One third of the trials were distractor-target trials, in which the location of the prime distractor was the same as the location of the probe target. One third of the trials were control trials, in which the locations of the stimuli on the prime display were unrelated to the locations of the stimuli on the probe display. The other third of the trials were no-selection trials. On these trials, a target was presented without a distractor on the prime display. The location of the prime target was unrelated to the locations of the stimuli on the probe display.¹ For all reaction time data, trials were deleted from the analyses if the response to either the prime display or the probe display was inaccurate.

A trial proceeded as follows. A fixation cross appeared for 500 msec, followed by the prime display. The prime display remained on the screen until the subject responded. The response was followed by either a 3,500-msec delay (4,000-msec RSI condition) or no delay (500-msec RSI condition). After the delay, a fixation cross appeared for 500 msec. The probe display was then presented and remained on the screen until the subject responded, which concluded the trial. The RSI between the probe display and the subsequent prime display was either 4,000 or 500 msec and was determined randomly. Thus, from the subject's perspective, displays were presented in a continuous stream, not in discrete prime-probe pairs.

Results and Discussion

Two dependent measures were recorded, reaction time and accuracy. For all the experiments reported in this paper, accuracy was high, approximately 98%, and very few effects were significant. Therefore, all the accuracy data and analyses are reported in the Appendix. Each Results section is divided into two sections: prime reaction time and probe reaction time. Also, median reaction times are reported.

Prime reaction time. Reaction times are reported in Table 1. Responses were faster on no-selection trials than on both control and distractor-target trials. However, this main effect for trial type was unaffected by PRSI, and response times did not vary as a function of PRSI. This was supported by a 3×2 analysis of variance (ANOVA), with trial type and PRSI as the independent variables. The main effect for trial type was significant [$F(2,88) = 75.08$, $MS_e = 192$, $p < .01$], but the main effect for PRSI [$F(1,44) < 1$, $MS_e = 502$], and the interaction between trial type and PRSI [$F(2,88) < 1$, $MS_e = 127$] were not.

These results suggest that the presence of a distractor on the prime display caused responses to be slowed by approximately 23 msec. Furthermore, this *prime distractor interference* effect did not vary as a function of PRSI.

Probe reaction time. Reaction times are reported in Table 1. Responses were slower on distractor-target trials than on both control and no-selection trials. Importantly, this main effect for trial type was not a function of either PRSI or RSI. A $3 \times 2 \times 2$ ANOVA was conducted, with trial type, RSI, and PRSI as the independent variables. The main effect for trial type was significant [$F(2,88) = 22.01$, $MS_e = 290$, $p < .01$], but the main effect for RSI was not [$F(1,44) < 1$, $MS_e = 867$]. The main effect for PRSI was not significant either [$F(1,44) < 1$, $MS_e = 387$]. Trial type did not interact with RSI [$F(2,88) < 1$, $MS_e = 318$]. Also, trial type did not interact with PRSI [$F(2,88) = 2.02$, $MS_e = 257$, $p = .14$]. There was no interaction between RSI and PRSI [$F(1,44) < 1$, $MS_e = 299$], nor was there a three-way interaction between trial type, RSI, and PRSI [$F(2,88) = 1.01$, $MS_e = 213$, $p > .10$].

These results suggest that the NP effect was not affected by PRSI. This result, and the lack of an interaction between trial type and RSI, are inconsistent with Neill et al. (1992). However, these findings support the results re-

Table 2
Reaction Times (With Standard Deviations) for Prime or Probe Display
as a Function of Trial Type and PRSI or RSI in Milliseconds: Experiment 2

	Trial Type						Interference	Priming
	Distractor-Target		Control		No Selection			
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Prime Display								
PRSI								
500	425	55	426	55	409	48	17	
4,000	426	48	430	55	409	59	21	
Probe Display								
RSI								
500	442	54	416	55	425	53		-26
4,000	441	57	419	51	421	51		-22

ported by Hasher et al. (1996) in suggesting that NP does not decay as RSI is increased and that NP is not affected by PRSI.

The purpose of the next experiment was twofold. First, I wanted to see whether the predictability of the presentation of displays had an effect on NP. Second, a potential criticism of Experiment 1 and of the two experiments reported by Hasher et al. (1996) is that each experiment lacks the power to detect an interaction between trial type and RSI and that, consequently, the argument against the episodic retrieval hypothesis is based on a null effect. Although this is a potential cause for concern, Experiment 2 provides a replication of Experiment 1 and allows for a direct comparison of the two time conditions (500–4,000 and 4,000–500) that should, according to ETR, differ the most.

EXPERIMENT 2

Method

Subjects. Forty undergraduates from the Georgia Institute of Technology participated in exchange for course credit.

Stimuli and Apparatus. The stimuli and apparatus were exactly the same as those in Experiment 1.

Procedure. The procedure was the same as that in Experiment 1, except for the following changes. Each subject performed six blocks of 50 trials. A trial proceeded as follows. A fixation cross appeared for 500 msec, followed by the prime display. The prime display remained on the screen until the subject responded. The response was followed by either a 3,500-msec delay (4,000-msec RSI condition) or no delay (500-msec RSI condition). After the delay, a fixation cross appeared for 500 msec. The probe display was then presented and remained on the screen until the subject responded. Their response was again followed by either a 3,500-msec delay or no delay. After the delay, another fixation cross was presented for 500 msec. This was followed by a filler display, which remained on the screen until the subject responded, which concluded the trial. The filler displays looked exactly like the other displays but were labeled *filler* because their only purpose for inclusion was so that the RSI between the prime and the probe could alternate from 500 to 4,000 msec consistently from trial to trial. The RSI between the filler display and the subsequent prime display was either 500 or 4,000 msec. As in Experiment 1, the displays were presented in a continuous stream, not in discrete prime-probe pairs.

As in Experiment 1, the RSI was either 500 or 4,000 msec. However, in this experiment, the subject was able to predict the upcoming

RSI, because it consistently alternated between 500 and 4,000 msec. The filler displays allowed me to consistently alternate the RSI from 500 to 4,000 msec while still having the RSI between the prime display and the probe display be either 500 or 4,000 msec.

Results and Discussion

Prime reaction time. Reaction times are reported in Table 2. As in Experiment 1, responses were faster to no-selection trials than to control and distractor-target trials. Also, this main effect for trial type was not a function of PRSI, nor was response time a function of PRSI. This was supported by a 3×2 ANOVA, with trial type and PRSI as the independent variables. The main effect for trial type was significant [$F(2,78) = 24.23$, $MS_e = 354$, $p < .05$], but the main effect for PRSI [$F(1,39) < 1$, $MS_e = 691$], and the interaction between trial type and PRSI [$F(2,78) < 1$, $MS_e = 247$] were not.

These results parallel those from Experiment 1. The presence of a distractor on the prime display caused responses to be slowed by approximately 19 msec, which is equivalent to the 23-msec prime distractor effect in Experiment 1. Indeed, an ANOVA with experiment added as a between-subjects variable indicated a lack of an interaction between experiment and trial type [$F(2,166) < 1$, $MS_e = 358$].

Probe reaction time. Reaction times are reported in Table 2. There was a significant NP effect, as evidenced by the slower response times to distractor-target trials than to control trials. There were no other significant effects. This was supported by a 3×2 ANOVA, with trial type and RSI as the independent variables. The main effect for trial type was significant [$F(2,78) = 36.81$, $MS_e = 341$, $p < .01$]. The effect for RSI was not significant [$F(1,39) < 1$, $MS_e = 471$], nor was the interaction between trial type and RSI [$F(2,78) < 1$, $MS_e = 309$].

These results support the finding in Experiment 1 and the results reported by Hasher et al. (1996) in suggesting that NP does not decay between 500 and 4,000 msec.

Comparing Experiments 1 and 2, it appears that the NP effect was larger in Experiment 2 (24 msec) than in Experiment 1 (11 msec). Indeed, an ANOVA with experiment as a between-subjects factor revealed a significant interaction between experiment and trial type [$F(2,166) = 9.34$,

Table 3
Reaction Times (With Standard Deviations) for Prime
or Probe Display as a Function of Trial Type and
PRSI, RSI, and PRSI-RSI in Milliseconds: Experiment 3

	Trial Type						Interference	Priming
	Distractor-Target		Control		No Selection			
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Prime Display								
PRSI								
500	605	78	608	79	560	84	48	
4,000	648	94	646	90	595	106	51	
Probe Display								
RSI								
500	613	86	613	86	598	80		0
4,000	656	99	646	91	640	88		-10
Probe Display								
PRSI-RSI								
500/500	604	90	612	89	595	87		8
500/4,000	646	99	649	99	640	93		3
4,000/500	622	91	613	86	600	76		-9
4,000/4,000	666	110	642	88	639	89		-24

$MS_e = 286, p < .01$]. Thus, a predictable RSI resulted in a larger NP effect than did an unpredictable RSI.

The results of Experiments 1 and 2 suggest three main conclusions. First, NP does not appear to decay between 500 and 4,000 msec. Second, PRSI does not have an effect on NP. Third, the NP effect is larger when RSI is predictable than when it is unpredictable.

Experiments 3 and 4 were conducted in an attempt to generalize the findings reported in the above localization tasks to identification tasks. Thus, Experiments 3 and 4 parallel Experiments 1 and 2 with regard to the RSI manipulations.

EXPERIMENT 3

Method

Subjects. Forty-three undergraduates from the Georgia Institute of Technology participated in exchange for course credit.

Stimuli and Apparatus. The apparatus was the same as that used in Experiments 1 and 2. However, in this experiment, the subjects were presented with two letters of different colors (red and green). They were instructed to respond to the identity of the red letter while ignoring the green letter. They responded by pressing a key on the computer keyboard. Four letters were used as stimuli: I, S, O, and X. Stickers marked with I, S, O, and X were attached to the S, C, L, and M keys, respectively.

Procedure. The procedure was exactly the same as that in Experiment 1, except that, on each display, the subject was presented with a red and a green letter and instructed to respond to the identity of the red letter. The letters were presented at the center of the computer screen and were somewhat superimposed.

Results and Discussion

Prime reaction time. Reaction times are reported in Table 3. Responses were faster on no-selection trials than on both control and distractor-target trials. However, this main effect for trial type was unaffected by PRSI. Responses were faster following a 500-msec PRSI than fol-

lowing a 4,000-msec PRSI. This was supported by a 3×2 ANOVA, with trial type and PRSI as the independent variables. The main effect for trial type was significant [$F(2,84) = 122.73, MS_e = 568, p < .01$], as was the main effect for PRSI [$F(1,42) = 41.87, MS_e = 2,285, p < .01$]. The interaction between trial type and PRSI was not significant [$F(2,84) < 1, MS_e = 543$].

These results suggest that the presence of a distractor on the prime display caused responses to be slowed by approximately 50 msec. Furthermore, this prime distractor effect did not vary as a function of PRSI. Also, responses were approximately 40 msec faster after a 500-msec PRSI than after a 4,000-msec PRSI.

Probe reaction time. Reaction times are reported in Table 3. Responses were faster on no-selection trials than on distractor-target and control trials. Response times did not differ for distractor-target and control trials. As with the prime displays, responses were faster following a 500-msec RSI than following a 4,000-msec RSI.

A $3 \times 2 \times 2$ ANOVA was conducted, with trial type, RSI, and PRSI as the independent variables. The main effect for trial type was significant [$F(2,84) = 9.74, MS_e = 1,142, p < .01$]. Tukey's HSD test revealed that responses were faster on no-selection trials than on control or distractor-target trials, which did not differ from each other. The main effects for RSI and PRSI were also significant [for RSI, $F(1,42) = 48.03, MS_e = 4,183, p < .01$; for PRSI, $F(1,42) = 5.92, MS_e = 864, p < .01$]. There was also an interaction between trial type and PRSI [$F(2,84) = 4.81, MS_e = 1,229, p = .01$]. None of the other interactions was significant (for all, $p > .20$). Thus, NP appeared only when the PRSI was 4,000 msec and was strongest when both the PRSI and the RSI were 4,000 msec.

One clear finding that emerges from this experiment is that the subjects responded approximately 40 msec faster following a 500-msec RSI than following a 4,000-msec

Table 4
Reaction Times (With Standard Deviations) for Prime or Probe Display
as a Function of Trial Type and PRSI or RSI in Milliseconds: Experiment 4

	Trial Type						Interference	Priming
	Distractor-Target		Control		No Selection			
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Prime Display								
PRSI								
500	608	75	617	71	560	79	57	
4,000	645	100	636	83	591	84	45	
Probe Display								
RSI								
500	629	80	607	71	610	78		-22
4,000	666	98	633	89	637	88		-33

RSI. Furthermore, NP was only observed following a 4,000-msec PRSI and was most reliable when both the PRSI and the RSI were 4,000 msec.

The presence of a PRSI \times trial type interaction might be taken as support for ETR. However, the pattern of NP effects across the four time conditions is not entirely consistent with ETR. This point will be addressed in the General Discussion section.

EXPERIMENT 4

Method

Subjects. Forty-one undergraduates from the Georgia Institute of Technology participated in exchange for course credit.

Stimuli and Apparatus. The stimuli and apparatus were the same as those used in Experiment 3.

Procedure. The procedure is exactly the same as that in Experiment 2, except that, on each display, the subject was presented with a red and a green letter and instructed to respond to the identity of the red letter.

Results and Discussion

Prime reaction time. Reaction times are reported in Table 4. As in the previous experiments, responses were faster to no-selection trials than to control and distractor-target trials. Also, this main effect for trial type was not a function of PRSI. As in Experiment 3, responses were faster following a 500-msec PRSI than following a 4,000-msec PRSI. This was supported by a 3×2 ANOVA, with trial type and PRSI as the independent variables. The main effect for trial type was significant [$F(2,80) = 71.52$, $MS_e = 999$, $p < .05$], as was the main effect for PRSI [$F(1,40) = 25.29$, $MS_e = 2,052$, $p < .01$]. The interaction between trial type and PRSI was not significant [$F(2,80) = 1.31$, $MS_e = 1,250$, $p > .10$].

The presence of a distractor on the prime display caused responses to be slowed by approximately 50 msec, which is equivalent to the 50-msec prime distractor effect in Experiment 3. Indeed, an ANOVA with experiment as the between-subjects variable revealed a nonsignificant interaction between trial type and experiment [$F(2,172) < 1$,

$MS_e = 1,525$]. Also, as in Experiment 3, responses were faster following a PRSI of 500 msec than following a PRSI of 4,000 msec.

Probe reaction time. Reaction times are reported in Table 4. There was a significant NP effect, as evidenced by the slower response times to distractor-target trials than to control trials, and this NP effect did not vary as a function of RSI. As with the prime reaction times, responses were faster following a 500-msec RSI than following a 4,000-msec RSI. This was supported by a 3×2 ANOVA, with trial type and RSI as the independent variables. The main effect for trial type was significant [$F(2,80) = 13.46$, $MS_e = 1,374$, $p < .01$]. The effect for RSI was also significant [$F(1,40) = 29.76$, $MS_e = 1,880$, $p < .05$]. The interaction between trial type and RSI was not significant [$F(2,80) = 1.25$, $MS_e = 728$, $p > .10$].

These results support the findings in Experiments 1 and 2 and the results reported by Hasher et al. (1996) in suggesting that NP does not decay between 500 and 4,000 msec. Thus, there are now six different experiments (Experiments 1-4, this paper, and Experiments 1 and 2 in Hasher et al., 1996) that fail to detect a decay.

Comparing Experiments 3 and 4, it appears that the NP effect was larger in Experiment 4 than in Experiment 3. Indeed, an ANOVA with experiment as a between-subjects factor revealed a significant interaction between experiment and trial type [$F(2,172) = 3.34$, $MS_e = 1,302$, $p < .05$]. Thus, as with the localization task, a predictable RSI resulted in a larger NP effect than did an unpredictable RSI.

GENERAL DISCUSSION

The purpose of this series of experiments was to examine the time-course of the NP effect. In all four experiments, a decay of NP was not detected. This is inconsistent with Neill et al. (1992) but is consistent with two experiments recently reported by Hasher et al. (1996). Also, in all four experiments, a PRSI effect similar to the one reported by Neill et al. was not detected. Again, this

finding is consistent with Hasher et al. (1996). Thus, four attempts here and two attempts by Hasher et al. (1996) have all failed to replicate the time-course effects presented as support for the ETR theory of NP.

In Experiment 3, the PRSI \times trial type interaction was significant, which one might argue is support for ETR theory. However, the pattern of NP observed in Experiment 3 is not consistent with an ETR account. According to ETR, the largest amount of NP should be observed in the 4,000–500 condition, and the smallest amount of NP should be observed in the 500–4,000 condition. Furthermore, equivalent NP should be observed in the 500–500 and 4,000–4,000 conditions. This clearly is not the case in Experiment 3.

One might still argue that the presence of a PRSI \times trial type interaction is sufficient evidence for ETR and that the overall pattern of NP is not critical to the theory (in other words, RSI manipulations affect trace discrimination but not trace strength). Furthermore, Neill (1997) has shown that, when the context at encoding (prime) matches the context at retrieval (probe), retrieval is more likely and NP is more robust. If we consider temporal factors, such as RSI, to be contextual information, combining the temporal discrimination idea with the contextual integration idea accounts for the results of Experiment 3. That is, temporal discrimination accounts for the PRSI \times trial type interaction, and contextual integration accounts for the larger NP effect in the 4,000–4,000 condition than in the 4,000–500 condition.

This is a particularly interesting account, because it could be embraced by either the dual-mechanism theory (Kane et al., 1997) or the temporal discrimination theory (Milliken et al., 1998). However, what is lacking is an explanation of why this pattern emerged in the identification task but not in the localization task. Thus, a focus of future research should be on factors that contribute to ETR. Particularly important are the implications for findings of individual and developmental differences in NP (for a review, see May, Kane, & Hasher, 1995). If both memory and attention processes contribute to NP, subject populations that fail to reveal NP may have a memory deficit, an attention deficit, or both.

There is another important finding to discuss. The NP effect is larger when RSI is manipulated consistently than when RSI is random. This is consistent with an inhibition account that assumes that the process of suppressing irrelevant information is controlled and effortful and that predictability allows better allocation of attentional control. Importantly, this result is not consistent with ETR theory, because the theory suggests that prime information is automatically retrieved and the probability of retrieval is not affected by predictability (Neill & Valdes, 1992).

In conclusion, there does not appear to be any evidence from the time-course literature that uniquely supports an ETR explanation of NP. Instead, when taken together, the results appear to support either a dual-mechanism ac-

count (Kane et al., 1997) or an integrative approach that incorporates both memory and attention processes (Milliken et al., 1998). More detailed investigations of the factors that affect retrieval and/or inhibition are still needed to fully explain NP.

REFERENCES

- ALLPORT, D. A., TIPPER, S. P., & CHMIEL, N. R. J. (1985). Perceptual integration and postcategorical filtering. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 107-132). Hillsdale, NJ: Erlbaum.
- CONWAY, A. R. A., TUHOLSKI, S. W., SHISLER, R. J., & ENGLE, R. W. (in press). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition*.
- DALRYMPLE-ALFORD, E. C., & BUDAYR, B. (1966). Examination of some aspects of the Stroop colour-word test. *Perceptual & Motor Skills*, *23*, 1211-1214.
- ENGLE, R. W., CONWAY, A. R. A., TUHOLSKI, S. W., & SHISLER, R. J. (1995). A resource account of inhibition. *Psychological Science*, *6*, 122-125.
- FOX, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review*, *2*, 145-173.
- GREENWALD, A. G. (1972). Evidence of both perceptual filtering and response suppression for rejected messages in selective attention. *Journal of Experimental Psychology*, *94*, 58-67.
- HASHER, L., STOLTZFUS, E. R., ZACKS, R. T., & RYPMA, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *17*, 163-169.
- HASHER, L., ZACKS, R. T., STOLTZFUS, E. R., KANE, M. J., & CONNELLY, S. L. (1996). On the time course of negative priming: Another look. *Psychonomic Bulletin & Review*, *3*, 231-237.
- HOUGHTON, G., & TIPPER, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. Carr (Eds.), *Inhibitory mechanisms in attention, memory, and language* (pp. 53-112). San Diego, CA: Academic Press.
- KANE, M. J., MAY, C. P., HASHER, L., RAHAL, T., & STOLTZFUS, E. R. (1997). Dual mechanisms of negative priming. *Journal of Experimental Psychology: Human Perception & Performance*, *3*, 632-650.
- MAY, C. P., KANE, M. J., & HASHER, L. (1995). Determinants of negative priming. *Psychological Bulletin*, *118*, 35-54.
- MILLIKEN, B., JOORDENS, S., MERKLE, P. M., & SEIFFERT, A. E. (1998). Selective attention: A re-evaluation of the implications of negative priming. *Psychological Review*, *105*, 203-229.
- MILLIKEN, B., TIPPER, S. P., & WEAVER, B. (1994). Negative priming in a spatial localization task: Feature mismatching and inhibition of distractor location. *Journal of Experimental Psychology: Human Perception & Performance*, *20*, 624-646.
- MOORE, C. M. (1994). Negative priming depends on probe-trial conflict: Where has all the inhibition gone? *Perception & Psychophysics*, *56*, 133-147.
- NAKAGAWA, A. (1991). Role of anterior and posterior attention networks in hemispheric asymmetries during lexical decisions. *Journal of Cognitive Neuroscience*, *3*, 313-321.
- NEILL, W. T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception & Performance*, *3*, 444-450.
- NEILL, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *23*, 1291-3105.
- NEILL, W. T., & VALDES, L. A. (1992). Persistence of negative priming: Steady state or decay? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *18*, 565-576.
- 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, & Cognition*, *18*, 993-1000.

NEILL, W. T., & WESTBERRY, R. L. (1987). Selective attention and the suppression of cognitive noise. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *13*, 327-334.

NEUMANN, E., & DESCHÉPPER, B. G. (1991). Costs and benefits of target activation and distractor inhibition in selective attention. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *17*, 1136-1145.

NEUMANN, E., & DESCHÉPPER, B. G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention. *Canadian Journal of Psychology*, *46*, 1-40.

ROBERTS, R. J., HAGER, L. D., & HERON, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General*, *4*, 374-393.

TIPPER, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology*, *37A*, 571-590.

TIPPER, S. P., & CRANSTON, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology*, *37A*, 591-611.

TIPPER, S. P., & MILLIKEN, B. (1996). Distinguishing between inhibition and episodic retrieval based accounts of negative priming. In A. F.

Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 337-364). Washington, DC: American Psychological Association.

TIPPER, S. P., WEAVER, B., CAMERON, S., BREHAUT, J., & BASTEDO, J. (1991). Inhibitory mechanisms of attention in identification and localization tasks: Time course and disruption. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *17*, 681-692.

YEE, P. L. (1991). Semantic inhibition of ignored words during a figure classification task. *Quarterly Journal of Experimental Psychology*, *43A*, 127-153.

NOTES

1. These trials allow a measure of the amount of interference caused by the presence of a distractor on the prime display. This *prime distractor interference* is measured by subtracting the mean response time on no-selection trials from the mean response time on control trials. It is important to gauge distractor interference, because we want to be sure that any observed differences in the NP effect are not caused by different amounts of interference (Tipper & Milliken, 1996).

APPENDIX

Table A1
Mean Accuracy as a Function of Trial Type and RSI (in Milliseconds) for Experiment 1

RSI	Trial Type		
	Distractor-Target	Control	No-Selection
Prime Accuracy			
500	98.15	98.80	98.19
4,000	98.56	98.15	99.03
Probe Accuracy			
500	98.61	98.56	98.61
4,000	97.59	98.38	98.66

Note—For prime: trial type, $F(2,88) < 1$, $MS_e = 0.0003$; RSI, $F(1,44) < 1$, $MS_e = 0.0003$; trial type \times RSI, $F(2,88) = 3.86$, $MS_e = 0.0003$, $p < .05$; For probe: trial type, $F(2,88) = 1.98$, $MS_e = 0.0003$, $p > .10$; RSI, $F(1,44) = 2.19$, $MS_e = 0.0005$, $p > .10$; trial type \times RSI, $F(2,88) = 1.92$, $MS_e = 0.0004$, $p > .10$.

Table A2
Mean Accuracy as a Function of Trial Type and RSI (in Milliseconds) for Experiment 2

RSI	Trial type		
	Distractor-Target	Control	No-Selection
Prime Accuracy			
500	98.44	98.96	99.17
4,000	98.65	98.33	98.65
Probe Accuracy			
500	98.23	98.65	98.44
4,000	98.33	98.13	98.65

Note—For prime: trial type, $F(2,78) < 1$, $MS_e = 0.0006$; RSI, $F(1,39) < 1$, $MS_e = 0.0008$; trial type \times RSI, $F(2,78) = 1.02$, $MS_e = 0.0004$, $p > .10$. For probe: trial type, $F(2,78) < 1$, $MS_e = 0.0005$; RSI, $F(1,39) < 1$, $MS_e = 0.0009$; trial type \times RSI, $F(2,78) < 1$, $MS_e = 0.0007$.

Table A3
Mean Accuracy as a Function of Trial Type and RSI (in Milliseconds) for Experiment 3

RSI	Trial Type		
	Distractor-Target	Control	No Selection
Prime Accuracy			
500	97.87	97.38	98.11
4,000	97.77	97.77	98.89
Probe Accuracy			
500	96.90	97.43	96.90
4,000	97.38	97.82	97.92

Note—For prime: trial type, $F(2,84) = 4.21$, $MS_e = 0.0005$, $p < .05$; RSI, $F(1,42) = 1.56$, $MS_e = 0.0005$, $p > .10$; trial type \times RSI, $F(2,84) = 1.17$, $MS_e = 0.0004$, $p > .10$. For probe: trial type, $F(2,84) = 1.43$, $MS_e = 0.0004$, $p > .10$; RSI, $F(1,42) = 3.01$, $MS_e = 0.0009$, $p = .09$; trial type \times RSI, $F(2,84) < 1$, $MS_e = 0.0003$.

Table A4
Mean Accuracy as a Function of Trial Type and RSI (in Milliseconds) for Experiment 4

RSI	Trial Type		
	Distractor-Target	Control	No-Selection
Prime Accuracy			
500	97.56	97.56	97.86
4,000	97.97	98.37	98.17
Probe Accuracy			
500	96.65	97.15	97.46
4,000	97.97	97.66	97.97

Note—For prime: trial type, $F(2,80) < 1$, $MS_e = 0.0007$; RSI, $F(1,40) = 1.60$, $MS_e = 0.0010$, $p > .10$; trial type \times RSI, $F(2,80) < 1$, $MS_e = 0.0007$. For probe: trial type, $F(2,80) < 1$, $MS_e = 0.0009$; RSI, $F(1,40) = 2.74$, $MS_e = 0.0014$, $p = .11$; trial type \times RSI, $F(2,80) < 1$, $MS_e = 0.0011$.