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Long and Short-term Negative and Positive Priming

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Negative priming is a selective attention phenomenon that refers to impaired performance to a target when the target appeared as a distractor in a previous trial (Tipper, 1985). Although DeSchepper and Treisman (1996) demonstrated long-term negative priming, a number of researchers have failed to replicate their findings. We present two empirical studies that demonstrate robust and general long-term negative priming without multiple stimulus repetitions. We also show that repetition increases and delay decreases the effect of negative priming. These findings confirm predictions of associative accounts of negative priming. Thus, negative priming may be seen not only as a product of selective attention, but also as an instance of general learning in the cognitive system.

Early theories of attention tended to focus on the object of attention. These theories emphasized the facilitating "spotlight" at the center of attention, and the remaining areas of visual space were largely ignored (e.g., Broadbent, 1958). More recently, however, researchers have developed evidence of an inhibitory effect of attention on objects that fall *outside* the spotlight. In particular, if some part of a visual display (either an object or a location) is to be ignored at some point in time, responses to that same item (or to one that is sufficiently similar) will be inhibited (i.e., slower or less accurate) at subsequent points in time. This inhibitory effect of ignoring an object has been termed *negative priming* (Tipper, 1985).

A typical negative priming experiment consists of pairs of visual displays. Before any stimuli are displayed, participants are told to respond to a certain aspect of each visual display. The aspect of the display that should be attended to is called the *goal-relevant* information or the *target*; the information to be ignored is the *goal-irrelevant* information or the *distractor*. For example, participants might be told to name the object shown in the center of the display and to ignore any other objects. If the distractor in the first (or *prime*) display becomes the target in the second (or *probe*) display, that pair of displays is called a *negative prime trial*. The signature response pattern is that participants are slower to respond to the target in the probe display of a negative prime trial than to the identical probe display in a control trial in which neither the target nor the distractor of the probe display had been presented in the prime display.

Negative priming is a robust phenomenon that has been demonstrated in different experimental paradigms, such as localization (e.g., Milliken, Tipper, Houghton, & Lupianez, 2000; Milliken, Tipper, & Weaver, 1994; Reder, Weber, Shang, & Vanyukov, 2003; Tipper, Weaver, & Milliken, 1995), identification (e.g., Neill, 1977; Neill & Kahan, 1999; Connelly & Hasher, 1993), judgment (e.g., Strayer & Grison, 1999; Neill & Valdes, 1992), classification (Yee, 1991) and categorization (MacDonald & Joordens, 2000). It has been studied using a variety of experimental materials, such as letters (e.g., Allport, Tipper, & Chmiel, 1985; Tipper & Cranston, 1985), words (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998), pictures (Tipper, 1985) and shapes (Strayer & Grison, 1999; DeSchepper & Treisman, 1996). Negative priming has not only been studied with normal adults, but it has also been investigated in different populations, such as children, older adults, and people with schizophrenic-like characteristics (e.g., Tipper & McLaren, 1990; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Beech, McManus, Baylis, Tipper, & Agar, 1991) to understand the general cognitive processes of selective attention. See Fox (1995), May, Kane, and Hasher (1995), and Neill, Valdes, and Terry (1995) for detailed reviews.

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Since this phenomenon was first described, two principal families of explanations have been proposed to account for it. The first posits that the role of attention in negative priming is one of inhibition or active suppression. In its initial formulation, this account claimed that when an object or location is ignored, the activation of its cognitive representation is suppressed (Neill, 1979). It was later modified to hold that although the representation of the ignored information remains active, inhibition acts to keep it from influencing one's response (Tipper & Cranston, 1985). According to these theories, negative priming occurs because this inhibition remains in force for some period of time after it is invoked. We refer to this as the *inhibitory* account of negative priming.

The second principal explanation is that negative priming occurs because of associations that form between instances of a stimulus and their subsequent responses, as in Logan's (1988) instance theory of automaticity (Erickson & Reder, 1998; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992). In this case, however, the responses in question are not the overt responses measured by the experimenter; they are the internal, attentional responses. As part of the process of making overt responses, however, participants are hypothesized to be making internal responses to focus attention on the stimulus to which they are to respond and consequently to ignore the irrelevant stimulus. According to the instance theory of automaticity, associations are then formed between each of the stimuli and the internal responses they evoked. On the probe display, when the previously irrelevant stimulus becomes relevant, it triggers its associated, internal ignore-response, which slows the overt response. We refer to this as the *attentional association* account of negative priming.

In this article, we examine three general predictions of associative memory theories. The first is that associations are retained over long time intervals, the second is that associations may be strengthened through repetition, and the third is that as the delay between encoding and testing (prime and probe, in this case) increases, the strength of the associations should decrease (Ebbinghaus, 1885/1964). Although these predictions might seem almost trivial to confirm, they have not been clearly established for negative priming. If these predictions cannot be confirmed, associative accounts of negative priming, including episodic theories (e.g., Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; Neill & Valdes, 1992; Neill et al., 1992), cannot be considered viable.

Some initial evidence of long-term negative priming has been demonstrated by DeSchepper and Treisman (1996). Several other researchers, however, have been unable to replicate those findings (Lowe, 1998; Strayer & Grison, 1999). Further, contrary to the predictions of an associative account, DeSchepper and Treisman found no evidence that repetition affected the strength of negative priming and only found an effect of delay in an analysis that included intervals as long as a month; they did not find an effect of delay with intervals up to 24 hours. We review these findings here.

DeSchepper and Treisman (1996) demonstrated long-term negative priming using a same-different judgment task with novel shapes. Participants were required to make judgments about whether or not a green shape on the left of the screen was the same as a white shape on the right of the screen. The distractor (goal-irrelevant information) in this paradigm was a red shape overlapping the green shape. The red shape (distractor) in the prime trials became the green shape (target) in the probe trials, while in the control trials, both the red shape and the green shape in the probe trials were different from the shapes in the prime trials. A long-term negative priming effect was observed to occur across at least 200 intervening trials and as long as one month with only a single presentation of the prime distractor.

DeSchepper and Treisman (1996) manipulated the number of times a prime stimulus was ignored before being presented as a probe. Although they found that participants' responses tended to be faster on *prime* trials after repeated presentations, they found no increase in the amount of negative priming on subsequent *probe* trials. DeSchepper and Treisman also examined the effect of the amount of delay between the prime and probe trials. Because they examined long-term negative priming, they were able to manipulate delay over a wide range of values. They observed an effect of delay only after one-week and one-month intervals were added. If the delay was 24 hours or less, they observed no effect. Moreover, the effect of delay they did identify after one week was averaged over two groups of participants. The groups were selected by examining immediate priming. Participants who showed positive priming given an adjacent two-display negative priming sequence showed an unexpected, *increased* degree of positive priming as the delay between prime and probe increased, whereas participants who showed negative priming given an adjacent two-display negative priming sequence showed decreased negative priming as the delay increased. They did not, however, report separate analyses of the two groups, so the effect of delay they found does not provide clear information about negative priming alone.

Strayer and his colleagues (Malley & Strayer, 1995; Strayer & Grison, 1999), however, called DeSchepper and Treisman's (1996) findings into question. They failed to replicate the results of DeSchepper and Treisman when only a single presentation of a novel prime distractor was used. Strayer and colleagues found that for negative priming to occur, a novel stimulus had to be repeated several times prior to being presented as a target. Malley and Strayer also evaluated the effect of the delay between prime and probe by comparing priming when no trials intervened between prime and probe with priming when one trial intervened. They found no effect of delay. These results, however, are consistent with those of DeSchepper and Treisman inasmuch as they examined delays much shorter than one week.

In contrast to the results of Strayer and colleagues (Malley & Strayer, 1995; Strayer & Grison, 1999), Lowe (1998) was able to find evidence of long-term negative priming. Like Strayer and colleagues, however, Lowe, only found negative priming when stimuli were presented multiple times. Moreover, his results indicated that long-term negative priming is highly context dependent. Whereas the studies described previously used a continuous paradigm in which prime and probe trials were intermixed, Lowe used a two-phase paradigm that included a training phase and a test phase. On each trial, two words were presented on the screen with the target in the “attend” color and the distractor in the “ignore” color. The participants’ task was to name the target. During the training phase, each target-distractor pair was repeated one, three, six or nine times. After a five-minute interval, participants were again presented with pairs of words and asked to name either the target or the distractor words from the training set. These were designated the positive and negative priming conditions, respectively. New pairs of words were also tested as control trials.

In his first experiment, Lowe (1998) found positive priming for *both* the positive and negative priming conditions. In this experiment, distractor words were paired with a different word in the test phase than in the training phase. In his third experiment, however, Lowe retained the pairs of words seen during training into the test phase. In the negative priming condition, he merely swapped colors so that the word that was the target during training became the distractor and vice versa. In this experiment, Lowe found positive priming in the positive priming condition and negative priming in the negative priming condition. Lowe also found that long-term negative priming depended upon multiple stimulus presentations. He found that long-term negative priming did not occur when word pairs were presented one or three times during training, but did occur when word pairs were presented six or nine times.

To summarize, although DeSchepper and Treisman (1996) were able to show long-term negative priming with a single prime presentation, Strayer and Grison (1999) were unable to replicate this finding (even on adjacent trials) without multiple prime repetitions (see also Malley & Strayer, 1995). Lowe (1998) was able to find evidence of long-term negative priming, but only when the same pairs of items were used in the prime and probe displays and with multiple priming trials. DeSchepper and Treisman found no evidence that repetition affected negative priming, whereas Malley and Strayer, Strayer and Grison, and Lowe could not obtain evidence of negative priming without repetition. Finally, it remains somewhat unclear whether there is an effect of of the amount of delay between prime and probe. Although DeSchepper and Treisman found an effect of delay once intervals of one week and one month were included, the effect they found included an increase in the amount of positive priming for a subset of their participants. This increase is difficult, if not impossible, to reconcile with an associative account of priming. The existing evidence, therefore, is either equivocal or fails to support the predictions of associative theories of negative priming. Before rejecting this class of theories, further evidence supporting or failing to support these predictions is necessary.

Having previously laid out general inhibitory and associative theories of negative priming, we note that it has become difficult to distinguish between them. Because early inhibitory accounts of negative priming held that negative priming reflects a suppression of the internal representation of the ignored item that persisted from the prime to the probe trial, these accounts predicted that there should be no long-term negative priming. This was especially true when other trials intervened between prime and probe (Houghton & Tipper, 1994). If this prediction still held, evidence of long-term negative priming would have posed a serious challenge to these theories. Tipper (2001), however, has argued that entire inhibitory processing episodes can be stored and retrieved (see also Tipper, Grison, & Kessler, 2003). This provides a mechanism by which an inhibitory theory can account for long-term negative priming, and means that evidence of long-term negative priming does not distinguish between these two classes of theories. Nevertheless, the empirical questions remain: Is there evidence for long-term negative priming? Is it necessary to have multiple repetitions of stimulus items to obtain negative priming—much less long-term negative priming? Does the amount of negative priming decrease over time?

Our principle goals, therefore, are to demonstrate negative priming over a long delay from prime to probe, to evaluate the effect of repeated primes, and to evaluate the effect of delay between prime and probe. Additionally, we seek to show that long-term negative priming does not necessarily require multiple stimulus presentations or identical contexts. We proceed as follows: First, we describe some preliminary results that suggest that long-term negative priming exists and that it can be readily accounted for by an associative memory theory. We then describe two new experiments designed to extend these findings. In the first, we demonstrate long-term negative priming after only a single distractor presentation, and we evaluate the effect of varying the delay between the prime and the probe. In the second, we replicate the finding of long-term negative priming with a delay that is extended over a much longer period. We again examine the effect of varying the delay between the prime and probe, and additionally, we evaluate the effect of varying the number of times the prime is presented.

Erickson and Reder (1998) provided an initial demonstration of long-term negative priming when a distractor was ignored multiple times prior to being presented as the target. In this experiment and in the other experiments presented in this article, the stimuli were numbers presented either in a bold or outline (or italic) font (Yee, Santoro, Grey, & Woog, 2000). The participants’ task was to identify the font of the number with the smaller value. Thus, the number with the smaller value was the target and the number with the larger value was the distractor. In probe trials, a number that had been the distractor in a previous prime trial became the target. In this experiment, there were *immediate negative prime* sequences in which a single prime and probe trial occurred consecutively, and there were *delayed negative prime* sequences in which 16 non-consecutive prime trials occurred and then a probe trial was presented at least five trials after the last prime.

In contrast to Malley and Strayer (1995) and Strayer and Grison’s (1999) findings, Erickson and Reder (1998) observed short-term negative priming ($M = -87$ ms, $SD = 113$ ms) for items that had been presented just once as a distractor and once as a target. Likewise, in contrast to Lowe (1998), they also observed long-term negative priming ($M = -70$ ms, $SD = 116$ ms) for probe displays that included

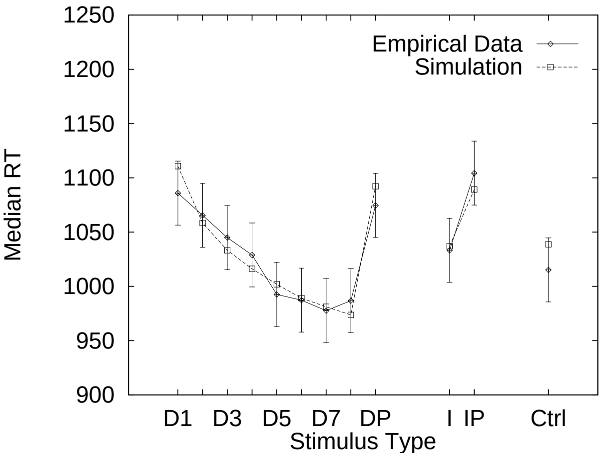

Figure 1. The best fit of the associative model to the empirical data. The stimulus types *Dn* and *I* denote delayed and immediate negative *prime* trials, respectively, the stimulus types *DP* and *IP* denote delayed and immediate negative *probe* trials, and stimulus type *Ctrl* denotes the control trials. Error bars indicate 95% confidence intervals around the mean.

changes in font, position, and the identity of the accompanying number after the critical item had been presented as a distractor 16 times before being presented as the target.

Erickson and Reder (1998) described an associative model that successfully accounted for a number of important aspects of these data. This model was an instantiation of the SAC[1] model of memory (e.g. Reder & Schunn, 1996; Schunn, Reder, Nhouyvanisvong, Richards, & Stroffolino, 1997), which may be thought of as a generic semantic network model of memory that most closely resembles the declarative memory structure in ACT (Anderson, 1983).[2] The goal of this model was to show that an associative explanation of negative priming, incorporating principles that have successfully accounted for a substantial number of memory phenomena, can account for long-term negative priming.

Although SAC's behavior was governed by several different parameters, *only a single scaling parameter was allowed to vary in fitting these data*. The other parameters were previously determined in an entirely different paradigm (Schunn et al., 1997). Erickson and Reder (1998) simulated this experiment by presenting the exact same sequence of trials seen by experimental participants to the model. The predicted response times are shown together with the data in Figure 1. In this figure, the means of participants' median correct response times and the means of the median predicted response times for pairs of stimuli from the delayed negative prime sequences, the delayed probe, the immediate negative prime, the immediate probe, and the control trials are shown. Here and throughout this article, the error bars are 95% confidence intervals computed using the distribution of participants' mean response times in each condition separately. Considering that this model utilized only a single free parameter, the fit is remarkable. The model accounted for 90% of the variance in the data ($SSE = 2,347$) and showed clear, qualitative negative priming effects.

Although these empirical results and the model fits provide some preliminary evidence for long-term negative priming and the ability of an associative theory to account for it, this study also raises new questions. First, the median lag between the last prime trial and the probe trial in the long-term negative priming sequences was just 10 trials (about 20–30 s). Although this is a relatively long period of time compared to what had been examined previously in most negative priming studies, it is a very short period of time compared to the intervals used in most associative learning studies. How long does negative priming last? A second question raised by this study is whether multiple primes are necessary for long-term negative priming. Short-term negative priming was observed after a single prime, and long-term negative priming was observed after multiple primes. If long-term negative priming were tested after a single prime, would it be observed? Would its magnitude be decreased relative to that observed following multiple primes as is predicted by most associative theories? These questions are addressed in the following experiments.

Experiment 1: Single-Presentation Long-Term Negative and Positive Priming

Experiment 1 attempted to achieve two primary goals: first, to observe whether long-term negative priming can be observed with only a single presentation of a distractor, and second, to examine the effect of the delay between the prime and probe trials. Whereas Erickson and Reder (1998) used negative priming sequences with repeated distractors, the present experiment used sequences consisting of a single prime trial followed at some subsequent point by a probe trial. Additionally, the lag between the prime and probe trials varied along four levels between 1 and 40.

A secondary goal was to address a possible alternate explanation for the negative priming effects observed by Erickson and Reder (1998). In their experiment, the likelihood of a number being a target or distractor varied depending upon the roles it had played in the past. Controlling for this factor was problematic because distractors needed to be presented repeatedly. In their experiment, given that a number had previously been presented as a target, it was 3.76 times more likely to be a target than a distractor. If a number had previously been presented as a distractor, it was 1.63 times more likely to be a distractor than a target. Although no participants reported being consciously aware of these probabilities, it is possible that they were implicitly affecting performance (Cary & Reder, 2002; Chun & Jiang, 1998; Kane et al., 1997; Reder et al., 2003).

To address this issue, we changed these probabilities by introducing two additional types of prime-probe pairings. To continue to examine negative priming, we retained pairings

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[1] SAC stands for *Source of Activation Confusion*.

[2] Note, however, that SAC and the declarative memory structure in ACT do differ subtly in their assumptions about link strength and more substantively in terms of the role of familiarity in recognition and other processes in memory.

in which the number that was the distractor on one trial became the target on some subsequent trial. We refer to this as a *distractor-target* pair. The first addition was a *target-target* pair in which a number served as a target on one trial and again as a target on some subsequent trial. The second addition was a *target-distractor* pair in which a number served as a target on one trial and a distractor on some subsequent trial. We also removed *distractor-distractor* pairs. Further, in this experiment, only the numbers that were required to repeat were repeated. All other numbers were used just once over the course of the experiment. This last constraint entailed that three-digit rather than two-digit numbers be used as stimuli.

Adding these two types of prime-probe pairings, using unique numbers where possible, and removing distractor-distractor pairs allowed us to control for the possibility that an implicit learning system was tracking targets and distractors over the course of the experiment. If a number was presented that had previously been presented as a target, it was equally likely to be a target or a distractor. Further, if a number was presented that had previously been presented as a distractor, it was certain to be a target because the distractor-distractor pairs were removed. If Erickson and Reder's (1998) previous findings of negative priming had been due to the implicit acquisition of these conditional probabilities, then this experiment should show *positive* priming for the distractor-target pairs.

Method

Participants

Fifty-eight undergraduate students from Carnegie Mellon University participated for research credit in an introductory psychology course.

Design/Materials

Three types of prime-probe pairs were varied factorially with four levels of prime-probe delay. Each of the twelve combinations was instantiated over 15 pairs of trials. The three types of prime-probe pairings were target-target, distractor-target, and target-distractor. In all the priming conditions, one number was repeated on two trials. In the target-target condition, the number appeared as a target in both trials. In the distractor-target condition, the number appeared first as a distractor and then as a target. In the target-distractor condition, the number appeared first as a target and then as a distractor. All of the other numbers appeared only once in the experiment. They were either paired with the numbers repeated in the above three conditions, or they were paired with one another in one of 160 control trials. The four delay conditions were immediate, short, medium, and long. The mean lag between the prime and probe trials in each of the twelve conditions is shown in Table 1.

Table 1
Mean lags, trial numbers, 5th and 95th trial number percentiles for probe trials in each condition in Experiment 1.

		Trial Number		
Delay	Lag	Mean	5th	95th
Distractor-Target Sequence				
Immediate	1.00 (0.00)	268 (152)	24	505
Short	5.43 (3.24)	262 (152)	23	491
Medium	20.03 (6.01)	252 (143)	36	480
Long	39.61 (6.31)	263 (135)	54	479
Target-Distractor Sequence				
Immediate	1.00 (0.00)	271 (154)	22	508
Short	5.78 (3.67)	258 (151)	26	494
Medium	19.77 (6.11)	265 (145)	45	489
Long	39.70 (6.16)	273 (137)	59	487
Target-Target Sequence				
Immediate	1.00 (0.00)	267 (155)	24	501
Short	5.87 (3.50)	267 (152)	30	497
Medium	19.93 (6.11)	261 (145)	39	487
Long	39.46 (6.47)	279 (139)	66	495

Note. Values enclosed in parentheses indicate standard deviations.

On each trial, the font of the target was selected randomly and independently so that for numbers that were presented twice, the probability that the response would be the same on the second presentation as on the first was .5. On each trial, the font of the distractor was always chosen to be the opposite of the font of the target.

The stimuli consisted of 898 three-digit numbers (101–998) with the exception of integer multiples of 111. The font (bold or outline) in which each number was displayed and the position (top or bottom) on the screen were randomly selected on each trial.

Procedure

All instructions to participants were presented on the screen. The instructions indicated that pairs of numbers would appear on the computer screen, and that the participant's task was to press either the button labeled "Outline" or the button labeled "Bold" on the button box, according to the type face of the smaller of the two numbers. The instructions emphasized that in determining the number on which the judgment was to be made, "smaller" referred to the value of the numbers, not to the physical size of the digits on the screen. As an example, two one-digit numbers, 8 and 3 appeared on the screen in boldface and outline type, respectively.

The experiment was run using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh IIci computer. Stimuli were displayed on a 14-inch display, and participants' response times were measured with accuracy to 1 ms using a button box. A label reading "The smaller number is:" was taped above the row of buttons on the button box. The left-most and right-most buttons on the button box were labeled "Outline" and "Bold", respectively. Numbers were displayed in 24-point type in Monaco font.

Each trial consisted of a fixation cross centered on the screen, followed by a pair of three-digit numbers presented one above the other and centered on the screen. Each three-digit number was approximately 7 mm high and 15 mm wide. The pair of numbers was separated by approximately 20 mm of vertical space. Within each trial type in each classification, half of the targets appeared in outline typeface, and half appeared in bold typeface.

Each trial proceeded as follows. A fixation cross appeared in the center of the screen for 500 ms, indicating that a pair of numbers was about to appear. The fixation cross disappeared and the two three-digit numbers appeared on the screen where they remained until the participant pressed either the Outline button or Bold button. Immediately following the button press, the fixation cross re-appeared to start the next trial. Participants were given the opportunity to take four breaks, evenly spaced over the 520 trials. Breaks were indicated by a message on the computer screen. Break duration was controlled by the participants and was typically less than one minute. The entire experiment, including administrative tasks and debriefing, lasted approximately 35 minutes.

Results

Median correct reaction times for each condition were calculated for each participant, and the mean of these medians was calculated. Mean error rates for each condition were also calculated.

The probe trials in each of the 12 conditions in the experiment were fairly evenly distributed. Nevertheless, there tends to be an overall speedup over the course of experiments. Therefore, priming was computed by comparing response times on probe trials with control trials that were in the same range of trials as the middle 90% of the probe trials to minimize any effect of a general speedup on the priming results. To permit better comparisons across the two dependent measures the same range of trials were used in the error rate analyses. These ranges are shown in Table 1. Both response-time and error-rate priming were computed by subtracting mean probe values from the control values so that positive priming is reflected by positive numbers and negative priming is reflected by negative numbers. Mean response times, error rates, and degree of priming in each condition are shown in Table 2. The degree of response-time and error-rate priming is presented graphically in Figures 2 and 3, respectively.

The data from each prime-probe type were examined separately in a two-way within-participant analysis of variance. The two factors were trial-type (probe vs. control) and delay (immediate, short, medium, and long). Associative theories predict that as the delay between prime and probe increases, priming should decrease. Therefore, the priming data were tested using a linear contrast across the four levels of delay. Although exact p-values are reported when $p \geq .0001$, all inferential tests were conducted with an alpha level of .05 (Wilkinson & Task Force on Statistical Inference, 1999).

Distractor-Target Prime-Probe Pairs

In this condition, participants' responses to probe trials were slower than to control trials, $F(1,57) = 74.90$, $MSE =$

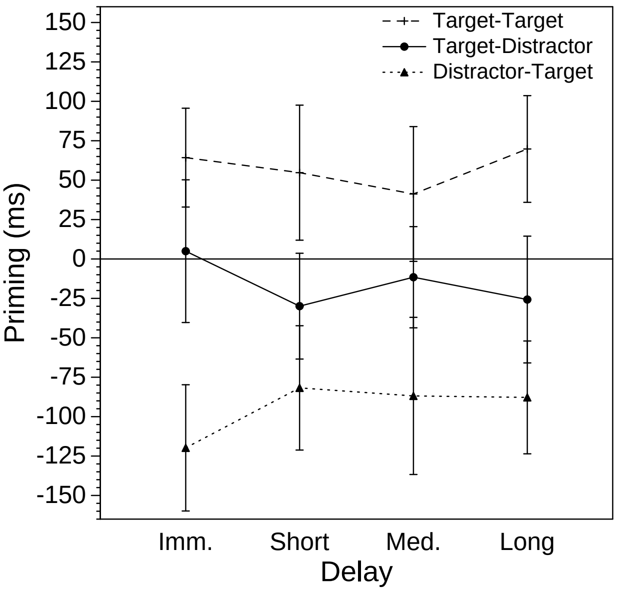

Figure 2. Mean of median reaction time (RT) difference between probe and control trials as a function of prime condition and prime-probe delay in Experiment 1. Error bars indicate the 95% confidence interval of the mean.

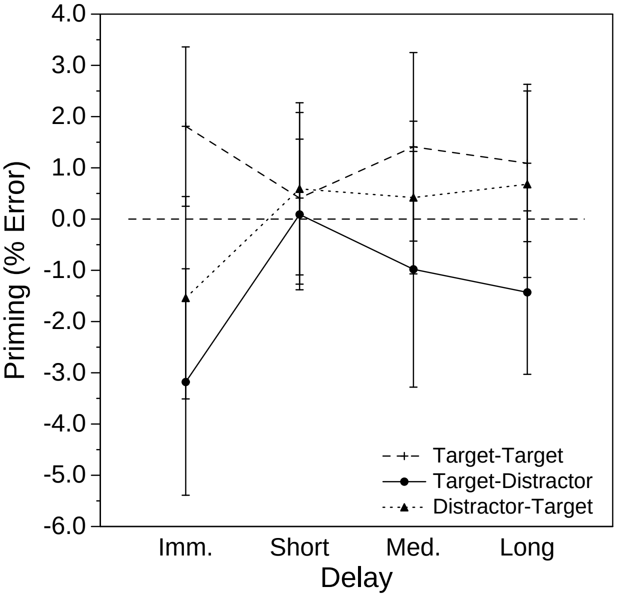

Figure 3. Mean error-rate difference between probe and control trials as a function of prime condition and prime-probe delay in Experiment 1. Error bars indicate the 95% confidence interval of the mean.

Table 2
Mean response times and error rates for control and probe trials, and amount of priming in each condition in Experiment 1.

	Response Time			Error Rate		
Delay	Control	Probe	Priming	Control	Probe	Priming
			Distractor-Target Sequence			
Immediate	1,080 (251)	1,199 (286)	−120 (152)	5.68 (4.67)	7.21 (9.76)	−1.54 (7.51)
Short	1,084 (253)	1,166 (275)	−82 (150)	5.70 (4.56)	5.11 (7.64)	0.59 (6.39)
Medium	1,084 (258)	1,171 (381)	−87 (190)	5.76 (4.68)	5.34 (6.49)	0.42 (5.68)
Long	1,082 (261)	1,170 (294)	−88 (136)	5.84 (4.78)	5.16 (7.40)	0.68 (6.92)
			Target-Distractor Sequence			
Immediate	1,078 (250)	1,073 (279)	5 (172)	5.68 (4.67)	8.86 (9.82)	−3.18 (8.40)
Short	1,082 (252)	1,112 (271)	−30 (128)	5.67 (4.56)	5.58 (7.31)	0.09 (5.58)
Medium	1,080 (257)	1,091 (250)	−12 (122)	5.81 (4.69)	6.79 (9.17)	−0.98 (8.76)
Long	1,080 (260)	1,105 (279)	−26 (153)	5.82 (4.86)	7.26 (7.97)	−1.43 (6.07)
			Target-Target Sequence			
Immediate	1,082 (252)	1,018 (297)	64 (119)	5.70 (4.73)	3.89 (7.48)	1.81 (5.92)
Short	1,083 (255)	1,028 (238)	55 (163)	5.71 (4.70)	5.31 (9.32)	0.41 (6.37)
Medium	1,082 (257)	1,041 (256)	41 (163)	5.77 (4.72)	4.36 (7.45)	1.41 (6.98)
Long	1,075 (255)	1,005 (244)	70 (129)	5.86 (4.96)	4.76 (7.81)	1.09 (5.83)

Note. Values enclosed in parentheses indicate standard deviations.

$13,702$, $p < .0001$. Thus, participants showed negative priming. There was no evidence of any trend showing differences in priming as a function of delay: Neither the interaction between trial type and delay nor the linear contrast examining this interaction were reliable, $F(3,171) = 0.72$, $MSE = 12,119$, $p = .54$, and $F(1,57) = 0.99$, $MSE = 24,232$, $p = .32$, respectively. Even at the longest delay, a single prime trial was sufficient to demonstrate significant negative priming, $t(57) = 4.91$, $p < .0001$.

Participants' error rates failed to show significant evidence of priming, $F(1,57) = 0.01$, $MSE = 27.14$, $p = .94$. Again, with error rates as with response time, neither the interaction between trial type and delay nor the linear contrast examining this interaction were reliable, $F(3,171) = 1.58$, $MSE = 20.51$, $p = .20$, and $F(1,57) = 2.75$, $MSE = 44.33$, $p = .10$, respectively. For these pairs, negative priming is reflected in a slowing of participants' responses, but is not shown by a reliable effect on error rate.

Target-Target Prime-Probe Pairs

Although the principal motivation for including this condition (and the target-distractor condition) was to eliminate cues that could potentially be used to predict whether a number was a target or a distractor, the full set of results shown in Table 2 may provide constraints on theories of negative priming as is discussed later. In this condition, participants' responses to probe trials were faster than to control trials, $F(1,57) = 24.36$, $MSE = 15,747.93$, $p < .0001$. Here again, there was no evidence of any trend showing differences in priming as a function of delay: Neither the interaction between trial type and delay nor the linear contrast examining the effect of delay was reliable, $F(3,171) = 0.52$, $MSE = 8,706$, $p = .67$, and $F(1,57) = 0.00$, $MSE = 13,290$, $p = .97$, respectively. As with negative priming, even at the longest delay, a single prime trial was sufficient to demonstrate significant priming, in this case, positive, $t(57) = 4.13$, $p < .0001$.

Likewise, participants' error rates showed evidence of positive priming. Participants responses to probe trials in this condition were more accurate than their responses to control trials, $F(1,57) = 8.38$, $MSE = 19.25$, $p = .0054$. Again, with error rates as with response time, neither the interaction between trial type and delay nor the linear contrast examining this interaction were reliable, $F(3,171) = 0.57$, $MSE = 19.97$, $p = .68$, and $F(1,57) = 0.09$, $MSE = 42.84$, $p = .77$, respectively. For these pairs, positive priming is reflected in a speedup of participants' responses and in a reduction of errors relative to the control trials.

Target-Distractor Prime-Probe Pairs

When presented with target-distractor pairs, participants' response latency was not significantly different in the probe than in the control condition, $F(1,57) = 2.53$, $MSE = 11,128.31$, $p = .1176$. These differences were not modulated by delay as shown by a test of the interaction of trial-type and delay and by a test of the linear interaction between these two factors, $F(3,171) = 0.70$, $MSE = 10,324$, $p = .55$, and $F(1,57) = 0.64$, $MSE = 24,543$, $p = .43$, respectively. The degree of priming for the target-distractor probes was, however, reliably different from both the distractor-target probes, $F(1,57) = 41.30$, $MSE = 8,653.17$, $p < .0001$, and the target-target probes, $F(1,57) = 33.69$, $MSE = 9,193.53$, $p < .0001$.

In this case, however, participants' error rates did show evidence of negative priming. Their error rates were higher when presented with probe trials than when presented with control trials, indicating *accuracy-based* evidence of negative priming, $F(1,57) = 6.90$, $MSE = 31.83$, $p = .0111$. Here again, with error rates as with response time, neither the interaction between trial type and delay nor the linear contrast examining this interaction were reliable, $F(3,171) = 0.57$, $MSE = 19.97$, $p = .68$, and $F(1,57) = 0.09$, $MSE = 42.84$, $p = .77$, respectively.

Our planned analyses indicate that for these pairs, negative priming priming is not reflected in a slowing of participants' responses, but is reflected in an increase in errors on probe relative to control trials. Although these results are in line with the predictions of associative theories of negative priming, this pattern of error rates should probably be viewed with some caution. It appears that in the target-distractor condition, the error-rate priming in the immediate condition is largely responsible for the finding of negative priming, whereas in the target-target and distractor-target conditions, the results seem to be more uniform across delay conditions. To examine this, we performed additional tests.[3] First, a contrast comparing immediate error-rate negative priming with the average of the three long-term conditions suggests that negative priming was greater in the immediate condition than in the long-term conditions, $F(1,57) = 4.62$, $MSE = 72.38$, uncorrected $p = .0358$. Second, a omnibus test comparing error rates on control versus probe trials in the three long-term conditions failed to show evidence of long-term error-rate negative priming, $F(1,57) = 2.21$, $MSE = 23.66$, uncorrected $p = .14$. To provide some context for these tests, when they were performed on the error rates for the target-target pairs, both yielded the opposite results: The contrast failed to suggest a difference between the immediate and long-term conditions, $F(1,57) = 0.90$, $MSE = 44.97$, uncorrected $p = .35$, whereas a test of the three long-term target-target conditions suggested that positive error-rate priming persisted beyond the immediate condition, $F(1,57) = 4.40$, $MSE = 18.59$, uncorrected $p = .0404$. In light of these patterns in the target-distractor data, therefore, we take a cautious stance that this experiment only provides the slightest evidence (if any) for long-term negative priming in this condition.

Discussion

Experiment 1 provides evidence of long-term negative priming in the critical distractor-target condition. In contrast to the findings of Erickson and Reder (1998), the present experiment demonstrated response-time short- and long-term negative priming conditions with just a single distractor presentation. This provides empirical evidence consistent with DeSchepper and Treisman's (1996) results. Participants also showed response-time and error-rate, short- and long-term positive priming in the target-target conditions. Finally, they showed error-rate negative priming in the target-distractor condition although we again caution that there was little evidence that negative priming in this condition persisted through the longer delays.

Table 3
Mean lags, trial numbers, 5th and 95th trial number percentiles for probe trials in each condition in Experiment 2.

		Trial Number		
Delay	Lag	Trial	5th	95th
1 Prime Presentation				
2	2.30 (0.46)	688.69 (110.89)	490	932
4	5.14 (1.11)	667.04 (174.15)	327	929
8	10.20 (2.20)	577.24 (223.66)	247	927
16	18.36 (3.48)	497.77 (253.23)	45	923
200	201.93 (4.46)	572.25 (223.33)	220	932
400	401.18 (2.75)	680.86 (163.27)	416	941
800	800.18 (0.42)	887.36 (47.54)	813	964
12 Prime Presentations				
2	2.22 (0.42)	732.34 (115.83)	625	948
4	4.69 (0.96)	659.97 (187.84)	387	932
8	9.36 (1.90)	551.81 (223.42)	280	916
16	18.03 (3.23)	535.56 (225.53)	244	908
200	200.48 (0.93)	621.60 (195.43)	369	925
400	400.99 (2.25)	718.59 (146.09)	494	939
800	800.15 (0.40)	927.37 (32.01)	876	970

Note. Values enclosed in parentheses indicate standard deviations.

A curious feature of the data from this experiment is the crossover of priming in the target-distractor and distractor-target conditions between the response-time and error-rate measures. Because participants had no way of knowing on each trial the condition from which the stimuli were drawn, this should not be seen as a simple speed-accuracy trade-off. In this experiment, when a target was repeated from a prime trial, either as a target or a distractor, it affected the error rate, and when a target had been seen previously, either as a target or a distractor, it affected response time.

This pattern of results, however, contrasts with those found in a word identification paradigm by Kane et al. (1997). They observed response-time but not error-rate negative priming in the distractor-target and target-distractor conditions. In the target-target condition, they observed marginally faster responses with a non-significantly increased error rate. Kane et al. further cite response-time negative priming in the target-distractor condition as a hallmark of episodic retrieval in this paradigm. Thus, they might argue that because we failed to find response-time negative priming in this condition, the present results should be explained by inhibitory processes. It remains for additional research to investigate the cause of the different patterns of performance in these two studies.

To summarize, Experiment 1 found evidence of long-term negative and positive priming after a single prime trial. No evidence was found, however, for an effect of the delay between the prime and probe trials. Inasmuch as this is a key

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[3] In performing these tests, we recognize that the failure to find an omnibus interaction between trial-type and delay entails that no Roy-Bose corrected post-hoc test will be significant. Nevertheless, we are providing these tests with uncorrected p-values to provide additional descriptive information.

Table 4
Mean response times and error rates for control and probe trials, and amount of priming in each condition in Experiment 2.

	Response Time			Error Rate		
Delay	Control	Probe	Priming	Control	Probe	Priming
			1 Prime Presentation			
2	1,087 (173)	1,252 (319)	−164 (254)	8.41 (9.00)	8.86 (17.3)	−0.45 (16.31)
4	1,104 (171)	1,229 (252)	−126 (169)	8.14 (8.49)	8.52 (13.4)	−0.38 (10.60)
8	1,115 (166)	1,233 (201)	−118 (117)	8.00 (8.19)	8.06 (9.36)	−0.05 (7.06)
16	1,141 (162)	1,242 (187)	−101 (113)	7.88 (7.80)	8.48 (10.1)	−0.60 (6.96)
200	1,117 (166)	1,255 (225)	−138 (141)	7.96 (8.12)	8.79 (11.3)	−0.83 (8.21)
400	1,095 (172)	1,227 (223)	−131 (126)	8.25 (8.68)	8.58 (10.8)	−0.34 (8.23)
800	1,060 (186)	1,181 (226)	−121 (121)	8.85 (9.80)	9.55 (12.5)	−0.69 (8.28)
			12 Prime Presentations			
2	1,080 (179)	1,280 (275)	−199 (228)	8.71 (9.47)	11.61 (17.9)	−2.90 (14.82)
4	1,098 (171)	1,267 (244)	−169 (185)	8.16 (8.59)	9.07 (15.9)	−0.91 (12.86)
8	1,113 (167)	1,339 (278)	−226 (192)	7.99 (8.27)	8.88 (13.5)	−0.89 (10.92)
16	1,116 (168)	1,332 (256)	−216 (167)	7.94 (8.21)	7.91 (11.9)	0.03 (9.32)
200	1,100 (171)	1,315 (269)	−215 (192)	8.11 (8.51)	10.30 (15.6)	−2.19 (12.54)
400	1,088 (173)	1,287 (262)	−199 (191)	8.44 (9.00)	8.51 (13.6)	−0.07 (10.25)
800	1,057 (195)	1,222 (281)	−166 (208)	9.01 (10.4)	9.38 (14.7)	−0.37 (13.31)

Note. Values enclosed in parentheses indicate standard deviations.

prediction for an associative account of negative priming, it is important to consider what might have caused this failure. First, it may be the case that there was no effect of delay. Second, there may have been an effect of delay, but this experiment lacked the power to detect it. The goal of Experiment 2 is to seek to overcome this second possible cause by incorporating a greater number of participants and by examining longer delays.

Experiment 2: Single- and Multiple-Presentation Long-Term Negative Priming

Like Experiment 1, Experiment 2 was designed to examine long-term negative priming. Although the principle motivation for Experiment 2 was to examine whether the failure to find an effect of delay between the prime and probe trials was due to a lack of power or a true lack of an effect, an additional motivation was to test the prediction of associative accounts of negative priming that repeatedly ignoring the critical item would strengthen negative priming. Because the inclusion of target-target and target-distractor prime-probe pairs seemed to have little effect on negative priming in Experiment 1, they were eliminated from Experiment 2.

Therefore, only two factors were manipulated. First, the delay between the last prime trial and the probe trial varied along seven steps from 2 to 800 (viz., 2, 4, 8, 16, 200, 400, 800). Second, the number of times the critical item was ignored in each sequence prior to being attended was either 1 or 12. Associative accounts of negative priming predict that as the delay between the last prime and the probe trials increases, negative priming should decrease, and that as the number of times the critical item is ignored increases, negative priming should increase.

Method

Participants

Two-hundred thirty-three undergraduate students from the University of California, Riverside participated for research credit in an introductory psychology course.

Design/Materials

Two levels of prime presentation (1 and 12) types of prime-probe pairs were varied factorially with seven levels of prime-probe delay (2, 4, 8, 16, 200, 400, and 800). When the prime trial was presented only once, 12 different two-trial prime-probe sequences were presented at each level of prime-probe delay. When the prime trial was presented 12 times, 6 different thirteen-trial repeated prime-probe sequences were presented at each level of prime-probe delay. This yielded 714 trials that were part of a negative priming sequence. The remaining 250 trials were control trials. When the negative prime trial was repeated 12 times, no two negative prime trials from the same sequence occurred on subsequent trials. The average lag between the last prime trial and the probe trial in each delay condition is shown in Table 3.

The stimuli were the same as were used in Experiment 1. The font in which each number was displayed (bold or italic) and the position on the screen (top or bottom) were randomly selected on each trial.

Procedure

All instructions to participants were presented on the screen. The instructions indicated that pairs of three-digit

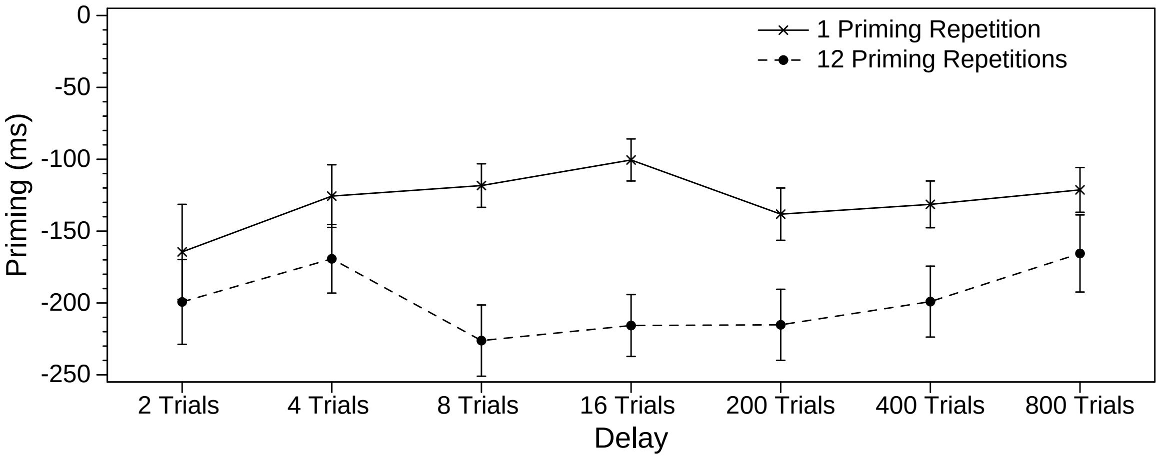

Figure 4. Mean reaction time (RT) differences between probe and control trials as a function of prime-repetition condition and prime-probe delay in Experiment 2. Error bars indicate the 95% confidence interval of the mean.

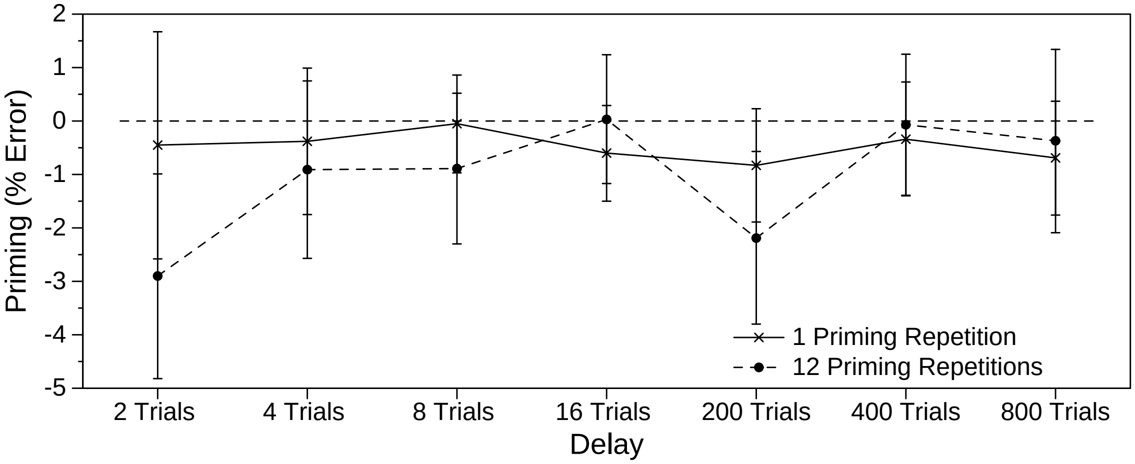

Figure 5. Mean accuracy difference between probe and control trials as a function of prime condition and prime-probe delay in Experiment 2. Error bars indicate the 95% confidence interval of the mean.

numbers would appear on the computer screen, and that the participants' task was to press either the button labeled "**B**" if the number with the smaller value appeared in a bold font or the button labeled "*I*" if the number with the smaller value appeared in an italic font.

The experiment was run using ePrime software on IBM PC-compatible computers. Stimuli were displayed on a 17-inch display, and participants indicated their responses by pressing keys on the numeric keypad. The "4" key was labeled with the letter "B" in bold font and the "6" key was labeled with the letter "I" in italic font. Numbers were displayed in 72-point type in Ariel font.

Each trial consisted of a blank screen followed by a pair of three-digit numbers presented one above the other and centered on the screen. Each three-digit number was approximately 34 mm high and 75 mm wide. The two numbers were separated by approximately 10 mm of vertical space. Approximately half of the targets appeared in italic typeface, and half appeared in bold typeface.

Each trial in Experiment 2 proceeded in the same manner as in Experiment 1 except that the 500 ms presentation of the fixation cross was replaced with a 500 ms blank screen. In Experiment 2, participants were given the opportunity to take five breaks, evenly spaced over the 964 trials. Breaks were indicated by a message on the computer screen. Break duration was controlled by the participants and was typically less than one minute. The entire experiment, including administrative tasks and debriefing, lasted approximately 50 minutes.

Results and Discussion

To reduce the effect of response time outliers, response times faster than 300 ms or slower than 2,500 ms were excluded from analysis (Ratcliff, 1993). This eliminated fewer than 5% of the responses from each tail of the distribution. Because the number of sequences in each condition differed, participants' mean rather than median correct reaction times were used in the analyses (Miller, 1988). Mean error rates for each condition were also calculated. As in Experiment 1, priming was computed by comparing correct response times on probe trials with control trials that were in the same range of trials as the middle 90% of the probe trials. These ranges are shown in Table 3. Mean response times and degree of priming and mean error rates and degree of priming in each condition are shown in Table 4, and the amount of priming for response times and error rates are shown in Figures 4 and 5.

The data were examined using a three-way within-participant analysis of variance. The three factors were trial-type (probe and control), number of prime presentations (1 and 12), and delay (2, 4, 8, 16, 200, 400, and 800 trials). Because associative theories of negative priming predict that as the delay between prime and probe increases, priming should decrease, the priming data were also tested using linear contrasts across the delay conditions. Four participants had at least one missing cell, so the data from 229 participants were analyzed.

Participants' responses to probe trials were slower than to control trials, indicating negative priming, $F(1,228) = 1,461.97$, $MSE = 29,231$, $p < .0001$. Response-time negative priming was greater when the primes were repeated 12 times than when they were only presented once, $F(1,228) = 131.41$, $MSE = 15,384$, $p < .0001$. Negative priming varied as a function of delay, $F(6,1368) = 3.36$, $MSE = 14,883$, $p = .0027$, and the effect of delay was different depending on the number of prime presentations, $F(6,1368) = 4.00$, $MSE = 14,263$, $p = .0006$.

The associative account of negative priming predicts a main effect of the delay between the last prime and the probe trial. As the delay increases, the amount of negative priming should decrease. This was tested using a linear contrast in which the levels of delay were used as the independent variable. The two-way linear interaction between trial type and delay indicated an overall decrease in the amount of negative priming as a function of delay, $F(1,228) = 4.77$, $MSE = 56,449$, $p = .0299$. In terms of Figure 4, this means that when the two curves are averaged together, the slope of the best-fitting line is significantly different from 0. This linear effect did not differ significantly as a function of the number of prime presentations, $F(1,228) = 2.50$, $MSE = 56,775$, $p = .1149$. Again, in terms of Figure 4, this means that when lines are fit to each of the two curves separately, the slope of those lines do not differ significantly from each other. Because the omnibus test indicated that the effect of delay on negative priming interacted with the number of priming repetitions yet the linear effect did not, higher order polynomial effects must have contributed to the significance of the omnibus test. These effects are discussed further in the General Discussion. As in Experiment 1, there was still significant negative priming at the longest delay even when participants had only been exposed to a single prime trial ($M = -121$, $SD = 121$), $t(233) = 15.36$, $p < .0001$.

Error-rate priming was analyzed following the same procedures as response-time priming. Participants' responses to probe trials were less accurate than to control trials, also indicating negative priming, $F(1,228) = 12.02$, $MSE = 85.97$, $p = .0006$. We failed to reject the null hypothesis of no effect of any of the remaining factors or their interaction on error rates. Error rates were not significantly different when the primes were repeated 12 times than when they were only presented once, $F(1,228) = 2.54$, $MSE = 58.04$, $p = .11$. Negative priming did not vary significantly as a function of delay $F(6,1368) = 1.17$, $MSE = 62.16$, $p = .32$, and the effect of delay was not significantly different depending on the number of prime presentations, $F(6,1368) = 1.10$, $MSE = 57.08$, $p = .36$.

General Discussion

Strong long-term negative priming effects were exhibited in both Experiments 1 and 2. Negative priming effects were obtained with only a single presentation of the prime, and these effects persisted for as long as 40 trials (approximately 90 s) in Experiment 1 and as long as 800 trials (mean delay 31.47 min., $SD = 3.88$ min.) in Experiment 2. Moreover, Experiment 2 provided evidence that the amount of negative priming decreases with increased delay between prime and probe, and that the amount of negative priming increased with repeated presentations of the prime. In this discussion, we address two questions: First, why were the negative priming effects so robust in these experiments? And second, how should these results be understood in light of associative and inhibitory accounts of negative priming?

Degree of Negative Priming Effect

One of the most striking differences between the present research and much of the previous negative priming research is the size of the negative priming effects. For example, when Malley and Strayer (1995) found negative priming, the average effect was 15 ms. Likewise, when Lowe (1998) found negative priming, the average effect was 23 ms; when DeSchepper and Treisman (1996) found negative priming, the average effect was 30 ms. In contrast, the mean negative priming effect over the three experiments in this article was 132 ms. We argue that there are at least two factors that distinguish the present research from many previous examinations of negative priming that might explain these differences in the degree of the negative priming effect. First, in the present studies, participants' responses were relatively slow. Second, the attend/ignore cues were conceptual rather than perceptual.

One reason the present studies might have yielded such large priming effects is that the task in these studies took a long time to complete relative to other tasks used to examine negative priming. On average, Malley and Strayer's (1995) participants took about 590 ms and Lowe's (1998) participants took about 634 ms to complete a word-identification task. DeSchepper and Treisman (1996) used a same-different judgment task in which participants responded after about 627 ms on average. The present studies required participants to make a judgment based on the value of two numbers on each trial and then identify the font style of the number with the smaller value. This task took, on average, about 1,078 ms for participants to complete, which is 1.64 times as long as these other studies. Given the relatively long response times in the present studies, it makes sense that absolute negative priming might be greater. The increase in the degree of negative priming in the present studies cannot, however, simply be attributed to the proportionately longer reaction times. Whereas the negative priming effects in the present studies are about 12% of the average reaction times, in these other studies, the negative priming effects were about 3.5% of the average reaction times.

An explanation for this disproportionate increase in negative priming is the use of a conceptual cuing task in the present experiments. In the experiments conducted by DeSchepper and Treisman (1996), Lowe (1998), and Malley and Strayer (1995), mentioned previously, the cue to ignore or to attend to a stimulus was the color of the stimulus. Participants were instructed to report the stimulus shown in one color and not to report the stimulus shown in another. Because color was used as the cue, participants only needed to process the distractors at a perceptual level. No conceptual processing was necessary to complete the task. In our experiments, participants reported the font of the number with the smaller magnitude. To give correct responses, therefore, participants needed to process both the target and the distractor to a conceptual level to identify the numbers' magnitudes. The deeper processing may have led participants to form stronger associations between the distractors and an ignore response in our studies (Craik & Tulving, 1975).

These results are consistent with the findings of Yee et al. (2000). In their studies, when participants used a conceptual task to select the item to attend to and then identified a perceptual feature of the stimulus as was done in the present studies, they obtained an average response time of 1,862 ms on probe trials and an average negative priming effect of 186 ms. These results are much more similar to the present results. The negative priming effect was 10% of the average reaction time. Note, however, that there were some differences between our findings and theirs. Unlike our Experiment 1, Yee et al. did not obtain positive priming with a conceptual selection task and a perceptual response task as was the case in our experiment. Whereas we obtained 58 ms of positive priming in the four target-target conditions, they obtained only 2 ms. The present negative priming results are also consistent with the findings of MacDonald, Joordens, and Seergobin (1999) who used a size judgment task much like Yee et al. (2000). Over their first four experiments (1A, 1B, 2A, and 2B), they obtained an average response time of 1,123 ms with 88 ms of negative priming. Thus, the size of their negative priming effect was 8%.

Predictions of Attentional Association Accounts

Attentional association accounts of negative priming such as those forwarded by Neill et al. (1992) and Erickson and Reder (1998) make three broad predictions about the results that should be expected in the present experiments. First, it should be possible for negative priming to last for long periods of time. Second, repeatedly presenting a stimulus as a distractor should increase the magnitude of negative priming when the stimulus is ultimately presented as a target. Third, increasing the number of intervening items between the time a stimulus is presented as a distractor and a target should decrease the degree of negative priming.

Duration of Negative Priming Effects

In Experiment 1, negative priming effects persisted over a delay of approximately 40 trials, and in Experiment 2, they persisted over a delay of 800 trials. Moreover, even after 800 trials, there was no indication that the degree of negative priming was decreasing. These findings are in accord with those of DeSchepper and Treisman (1996), who found negative priming effects that lasted as long as a month. Moreover, we were able to find long-term negative priming using different pairs of stimuli in probe trials than were used in the prime trials. This stands in contrast to the findings of Lowe (1998), who only found long-term negative priming when the stimuli in the prime and probe trials were identical except for their color. These findings also differ from those of Strayer and Grison (1999) who were unable to find negative priming effects with novel stimuli. The duration of negative priming effects in the present experiments conform with the predictions made by attentional association accounts of negative priming.

Repeated Distractor Presentation

In Experiment 2, primes were presented 1 or 12 times as distractors before appearing as a target. The magnitude of the priming effects was greater after 12 prime presentations than after 1 presentation, although negative priming was found in both conditions (even after a delay of 800 trials). This finding is consistent with the predictions of attentional association accounts of negative priming. When items are repeatedly paired, they tend to be associated more strongly (Hellyer, 1962; Pirolli & Anderson, 1985). Within an attentional association account of negative priming, this stronger association may increase the speed and the reliability of the initial "ignore" response to the previously ignored stimulus.

This finding that the distractor sequence length impacts the amount of negative priming may explain why Lowe (1998) and Strayer and Grison (1999) were unable to find evidence of negative priming after a single presentation. Because their effect sizes were so small, their experimental methodologies may have required the added effect obtained by multiple repetitions. In light of the present findings, however, it seems likely that there is not a qualitative difference between single and multiple repetitions, but merely a quantitative one. The present findings, as well as those of Strayer and colleagues and Lowe, contradict those of DeSchepper and Treisman (1996) who found no effect of repetition on negative priming. One possible explanation for this difference is that the studies that obtained repetition effects all used distributed presentations of repeated primes whereas

DeSchepper and Treisman used massed presentations. The effect of massed presentations is typically smaller than that of distributed presentations (Bahrick, 1979; Glenberg, 1976).

Prime-Probe Delay

Clearly a critical finding regarding memory is that it changes over time. As just discussed, practice and repetition make retrieval faster and more accurate (Hellyer, 1962; Pirolli & Anderson, 1985), whereas delays and intervening items make retrieval slower and less accurate (Anderson & Schooler, 1991; Ebbinghaus, 1885/1964). Attentional association accounts of negative priming, therefore, predict that as the number of intervening items between a prime trial and a probe trial increases, the degree of negative priming should decrease. Hence, in both experiments, planned linear contrasts were performed to check for this decrease. In Experiment 1, probe trials were presented after delays of approximately 1, 6, 20, and 40 trials. Negative priming was found in all four conditions. An omnibus test of the effect of delay indicated that the magnitude of the negative priming effect did not differ significantly between the conditions, and a linear contrast likewise found no significant systematic decrease. In Experiment 2, probe trials were presented with delays of approximately 2, 4, 8, 16, 200, 400, and 800 trials. Negative priming was found in all seven conditions. Critically, in this experiment, an omnibus test indicated that the magnitude of the negative priming effect did differ significantly between conditions and a linear contrast found a significant decrease in the amount of negative priming as the prime-probe delay increased.

This finding confirms and makes more general the findings of DeSchepper and Treisman (1996). They found an effect of delay only when the delay was longer than 24 hours. Moreover, they failed to observe short- or long-term negative priming in these experiments unless they partitioned their participants. Once this partitioning was complete, they found both *decreased* negative priming and *increased* positive priming as a function of delay. In the present Experiment 2, overall negative priming and the effect of delay are observed without the need for the partitioning of participants.

Although this experiment did find the predicted effect of delay, visual inspection of Figure 4 suggests that this effect is more complex than a simple linear (or linear plus quadratic) effect. One possible explanation for this added variability is that the effect measured as a function of delay in this experiment has more than one component. Manipulations of the delay between the last prime and the probe trial were concomitant with changes in the trial number of the probe trial, especially in Experiment 2 (see Table 3). Therefore, the degree of negative priming as a function of delay is also a function of the probe trial number. Even though control trials were selected from the same range trials as the probe trials, the curves seen in Figure 2 may be a function of both delay and trial number. Because the delay between the last prime and probe trial was as long as 800 trials and Experiment 2 only contained 964 trials, this relationship between delay and trial number was difficult to avoid. It will be important in future experiments to lengthen the experiments so that delay can be manipulated separately from trial number to test this critical variable.

Predictions of Inhibitory Accounts

According to early inhibitory accounts of negative priming, negative priming reflects a suppression of the internal representation of the ignored item that persists from the prime to the probe trial. These accounts could not explain long-term negative priming, especially when other trials intervened between prime and probe as in the present experiments. Tipper (2001) has argued, however, that entire inhibitory processing episodes can be retrieved (see also Tipper et al., 2003). Whereas according to the associative accounts, “ignore” responses (or tags) are associated with the stimuli, according to Tipper’s explanation, inhibitory internal representations are associated with the stimuli. In both cases, these responses or representations can be retrieved to cause long-term negative priming. Beyond the general prediction that long-term negative priming is possible under Tipper’s account, there seem to be no specific predictions about how it decays over time or the effect of repeated primes. Therefore, the plausibility of this theory could not be evaluated relative to the results obtained in the present studies. In the future, it will be important for inhibitory theorists to specify their theory in more detail so that it can be tested.

Conclusions

We have shown support for three predictions of associative accounts of negative priming: that people should show long-term negative priming, that negative priming should decrease as the delay between prime and probe increases, and that negative priming should increase with repeated presentation of the prime. These finding resolve previous ambiguous results regarding these phenomena and provide evidence for the plausibility of an associative account of negative priming. An important additional empirical result is that we obtained long-term negative priming (over 30 min.) with only a single prime. Further, negative priming did not require contextual similarity as was argued by Lowe (1998). These findings provide evidence suggesting that negative priming may reflect general learning properties of the cognitive system. Future research is necessary to elucidate the temporal properties of negative priming. We anticipate that this will eventually facilitate empirical integration of selective attention and general learning. Developing computational models within unified cognitive architectures will help capture the quantitative nature of general cognitive mechanisms operating across different empirical domains (Erickson & Reder, 1998; Gotts & Plaut, 2004).

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