AN INVESTIGATION OF NEGATIVE PRIMING:
THE ROLE OF COGNITIVE INHIBITION

by

KELLY FRUDD

(Under the direction of Dr. Katherine Kipp)

ABSTRACT

Negative priming refers to the slowed response to a stimulus that was previously ignored. One of the potential problems with the negative priming literature is the inconsistency of when and how much negative priming is obtained from a variety of experimental paradigms examined in different laboratories. Of particular interest in this study, was how the magnitude of negative priming may change according to the exact timing of the parameters of the experiment. This study investigated the negative priming effect across four stimulus onset asynchronies and two interference conditions. One hundred and six university undergraduate students participated in a lexical decision task. Participants were presented with a series of negative priming and control prime-probe trial pairs. Reaction times and error rates were recorded and analyzed. The Cognitive Failures Questionnaire was given to participants and compared with performance measures on the lexical decision task. Experimental results were discussed within the framework of negative priming literature.

INDEX WORDS: Negative Priming, Cognitive Inhibition, Lexical Decision
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by

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INTRODUCTION

Negative priming is generally defined as slowed responding to a stimulus on a given trial that had to be ignored on a previous trial (Tipper, 1985). Presumably, ignoring part of a stimulus display in order to attend to a different part of the display requires inhibiting the to-be-ignored material. By contrast, priming is defined as faster responding to a stimulus on a given trial that was in the focus of attention on a previous trial. The typical negative priming paradigm involves prime and probe stimulus displays rapidly presented in sequence on a computer monitor. The prime display consists of a target to which a participant must attend, and a distractor that must be ignored. After a variable inter-stimulus interval (usually a few hundred milliseconds), the probe is displayed that also consists of a to-be-attended target and a to-be-ignored distractor. Once the required response (e.g., naming, lexical decision, matching, etc.) to the probe has been given, a short inter-trial interval of a few seconds typically ensues until the next prime-probe pair is presented. Mean response latencies and error rates are measured for a series of such trial pairs.

Typically, there are two types of prime-probe trial pairs presented in negative priming studies: negative priming (or “repetition”) trials and control (or “non-repetition”) trials. Negative priming trials consist of pairs in which the “to-be-ignored” distractor item in the prime display becomes the “to-be-attended-to” target item in the probe display. In this fashion, information that was to be inhibited must now receive focal attention. By contrast, control trials consist of no relation between any items on prime and probe pairs.
The negative priming phenomenon is obtained when longer response latencies (and/or greater error rates) occur on negative priming trials as compared with control trials.

**Hypothetical Interpretation of Negative Priming: Cognitive Inhibition**

One explanation of the negative priming effect appeals to the concept of cognitive inhibition (Fox, 1995; May, Kane & Hasher, 1995; Neumann & DeSchepper, 1992; Tipper, 1985; Tipper & Driver, 1988). Cognitive inhibition is a construct analogous to a suppression process that prevents task-irrelevant information from receiving further cognitive processing for some limited period of time (Harnishfeger, 1995). Because participants in negative priming experiments are typically unable to identify distractor material, as well as are unaware of the negative priming contingency, one might assume that distractor items were not processed (i.e., truly totally ignored). However, the mere existence of the negative effect strongly contravenes such an assumption (Neill, 1977, 1979; Neill & Westberry 1987; Neumann & DeSchepper, 1992; Tipper, 1985; Tipper & Cranston, 1985). After all, distractor material is responded to more slowly (or with more errors). A model of cognitive inhibition accounts for the negative priming effect by a process that actively suppresses (inhibits) further processing of the prime distractor for a period of time. Not only is this distractor irrelevant for completing the prime task, but also further activation of this distractor item may, in some cases, cause competition with the activation of the target on the probe trial and thereby hinder the participant responding to the probe. On the negative priming trials, when the prime distractor becomes the probe target, its inhibitory status must be actively overcome in order to be fully processed in the probe display and receive a response. This release from
overcoming or releasing information from inhibition is believed to require time, thereby producing the longer response latencies associated with negative priming trials relative to control trials (Laplante, Everett & Thomas, 1992; Lowe, 1985; May et al., 1995; Neumann & DeSchepper, 1992; Yee, 1991). By this logic, participants who exhibit larger negative priming measures are thought to be better (i.e., more efficient) inhibitors relative to those who show little or no negative priming on the negative priming trials (May et al., 1995). Good inhibitors should inhibit the irrelevant items more strongly and hence, need more additional activation to overcome this inhibition, taking more time relative to the poor inhibitors whose weak inhibition of irrelevant stimulus items would be easier (and faster) to overcome. Because individual differences in overall cognitive processing speed may vary, the relative difference between performance on the negative priming trials and the control trials designates a particular participant as a good or poor inhibitor.

The Research Problem and Hypothesis

The negative priming literature is comprised of a complex and often contradictory variety of experimental findings. Many researchers agree that cognitive inhibition plays an important role in explaining the negative priming effect. (Fox, 1995; May et al., 1995; Neumann & DeSchepper, 1992; Tipper, 1985; Tipper & Driver, 1988) But, not all agree that cognitive inhibition is being measured in every variant of a negative priming experiment or further, that cognitive inhibition necessarily produces the slowing often observed in negative priming experiments (Kane, May, Hasher, Rahhal & Stoltzfus, 1997; Neill, 1997; Neill & Valdes, 1992; Neill, Valdes, Terry & Gorfein, 1992). Failures to replicate the negative priming effect have been ascribed to a variety of factors including differences in discriminability of experimental stimuli (Kane et al., 1997), lack
of inhibitory ability in certain populations of participants (Kane et al., 1997; May et al., 1995), and presence or absence of probe interference (Allport, Tipper & Chmiel, 1985; Neill, 1997; Neill & Valdes, 1992; Neill & Westberry, 1987; Tipper & Cranston, 1985; Yee, 1991).

The hypothesis explored in this paper is that a model of cognitive inhibition could explain existing discrepancies (i.e., a failure to replicate). More specifically, a simple manipulation of timing could account for some of the discrepant results. The hypothesis presented here is that the onset asynchrony between the prime display and the participant’s response to the probe is of crucial importance. The cognitive inhibition model implies that prime distractors are first briefly activated, followed by a period during which inhibition of distractors occurs. This period of maximum inhibition is then followed by dissipation of the inhibitory effect after sufficient time has again elapsed (Laplante et al., 1992; Lowe, 1985; May et al., 1995; Neumann & DeSchepper, 1992; Yee, 1991). Consequently, inhibition of the distractors will rise over the early part of this period, reach a maximum, and then dissipate as soon as the process of inhibition is “turned off.” If a participant is making a response selection involving processing of an inhibited item during some window or period of effective inhibition (i.e., when inhibition is at a maximum), a slowed (or less accurate) responding results. On the other hand, if selecting a response (to the probe in negative priming-type trials) occurs either before cognitive inhibition has had time to accrue or after cognitive inhibition has dissipated, no negative priming will result. In fact, priming in the positive direction would be predicted in some situations because immediately before the inhibitory period, distractor items may receive cognitive activation. Within the negative priming literature, many experiments
involve either direct or indirect manipulations of difficulty (Allport et al., 1985; Kane et al., 1997; May et al., 1995; Neill, 1997; Neill & Valdes, 1992; Neill & Westberry, 1987; Tipper & Cranston, 1985). If participants take longer to respond in certain conditions (as compared to other conditions) or if participants belong to a population who are typically slower at some cognitive tasks (i.e., older adults or certain clinical populations), their response to the probe task could occur after inhibition has peaked and dissipated. Alternatively, if participants respond more quickly than is usual, responses may occur before inhibition has had time to accrue fully to its maximum. Due to a restricted (or inappropriate) range of SOAs (stimulus onset asynchronies between the prime and probe displays), some experiments may miss measuring an inhibitory (negative priming) effect.

The experimental literature on negative priming contains several findings that could be used to support the hypothesis just proposed. Kane et al. (1997) found three times more negative priming on degraded probe-target trials (as compared to regular probe-target trials). This outcome could suggest that if the task is made more difficult, the longer response latencies to the probe could be serving to synchronize the window of maximal inhibition (of the prime distractor) with the window of time when the participant is making a response to the probe target.

Using a negative priming Stroop (1935) paradigm, Laplante et al. (1992) studied the time course of cognitive inhibition in different subtypes of schizophrenics, clinically depressed individuals, and healthy young adults as controls. By varying the time between onset of the prime and probe stimuli, the experimenters were able to map out the approximate window of inhibition in their particular paradigm. They found that the time courses of the accrual and dissipation of inhibition were different for these different
populations. This outcome could possibly explain the covariance in the size of the negative priming effect and the difficulty level of the probe task. By the same token, those outcomes (and the current hypothesis) may help to explain why some populations, such as older adults, may not show negative priming in some studies (Kane et al., 1997). For example, older adults could have functional inhibitory capacity, but because the time sequence of cognitive processing is different for them, their window of maximal inhibition lags a bit behind that of the younger adults (Hasher, Stoltfuz, Zacks & Rypma; 1991).

Other researchers have reported that in conditions in which there is no interference on the probe trials, there is no negative priming. Milliken, Joorens, Merikle and Seiffert (1998) conducted a study in which interposed red and green words were used as targets and distractors. They found that when the probe trial did not require a choice (e.g., when there was only one word in the probe display), priming rather than negative priming occurred. According to the present hypothesis, these results could have been obtained because the responding to a probe requiring a very easy response might occur before inhibition (of the prime distractor) has fully accrued. The priming could be due to the probe answer given during the hypothesized window of distractor activation prior to the accrual of inhibition. Milliken, Lupianez, Debner, and Abello (1999) found that participants were, in fact, significantly faster (on average 50 ms faster) on non-choice (i.e., no-interference) trials compared with trials of the same type that included distractors on the probes.

In addition, studies in which instructions to participants emphasized speed over accuracy of response produced (positive) priming on negative priming trials (Neill &
Westberry, 1987; Neumann & DeSchepper, 1992). The cognitive inhibition model can also explain this finding. Speedier than normal response to the probe may have resulted in the participants making their response selection during the brief period of initial activation of distractor stimuli before inhibition had fully accrued. The results of the studies just reviewed suggest that the degree of negative priming obtained may be manipulated via the manipulation of task difficulty. These same studies also suggest that a paradigm measuring negative priming at a variety of SOAs (between the prime and probe displays) could be advantageous for mapping out the time course of the negative priming effect. One of the potential problems with the negative priming literature is that researchers may compare their experiments with those of other researchers in different laboratories using different experimental paradigms. For example, comparisons have been made among studies with varying types of stimuli, degree of task difficulty, and type of task response. Consequently, differences in results could be erroneously attributed to the nature of the stimuli or type of task. According to the present hypothesis, these variables only mediate the amount of negative priming observed in a situation via the amount of inhibition acting on the probe stimuli at the time of probe response selection. There is a need for a controlled investigation of negative priming across different timing and difficulty conditions using the same experimental paradigm.

There have been previous studies in which investigators have studied negative priming effects over time using a variety of SOAs. Most of these studies involved either Stroop (Laplante et al., 1992; Lowe, 1985; Neill & Westberry, 1987) or location-based (Neill et al., 1992; Tipper et al., 1991) negative priming tasks. The current investigation focuses on object-based (i.e., semantic) negative priming in a lexical-decision task. For a
discussion of location-based negative priming, see Park and Kanwisher (1994) or Tipper, Weaver, Cameron, Brehaut and Bastedo (1991). Past studies in which object-based negative priming was examined, involved the time-course of negative priming without controlled manipulations of task difficulty (except, of course, for the negative priming versus control manipulations). There have also been previous studies which compared probe interference-present versus interference-absent (i.e., task difficulty) negative priming effects (Lowe, 1979; Milliken et al., 1998, 1999; Neill & Valdes, 1992; Neill, et al., 1992), but these studies have been either location-based in focus or involved only a pair of SOAs and may have missed the full range of activation and inhibitory processing events.

According to the present hypothesis, positive priming, negative priming, or no effect will be observed depending on the cognitive status of the prime distractor information at the time of probe response selection. It is essential to keep in mind that the prime distractor is the same item as the probe target on repeated item trials. The availability of the probe target identity during response selection is determined (at least in part) by the inhibitory status of the item since its presentation as the prime distractor. The availability of this item identity during probe target selection then determines whether priming will occur and whether it will be in the positive or negative direction.

See Figure 1 for examples of hypothesized results at short (a), moderate (b), and long (c) SOAs. Processing of the prime distractor begins with \textit{onset} of the prime. Response selection to the probe cannot be made until the SOA has passed and the probe is presented. As SOA changes, so too does the window of time when the probe response selection is being made relative to the onset of the prime display. For shorter SOAs, the
Figure 1. Model of inhibition/activation across SOA for (a) short SOA (b) moderate SOA, and (c) long SOA conditions. The curved line represents processing of the prime distractor/probe target item (for a negative priming trial).
probe response may be made during the initial period of prime distractor activation, and result in positive priming. For moderate SOAs, the probe response may be made when prime distractor inhibition is effective. Therefore, the result is negative priming. For longer SOAs, the probe response may be made after prime distractor inhibition has dissipated. The result in this case, is lack of an effect.

See Figure 2 for examples of hypothesized results at more difficult (a), and easy (b) levels of probe difficulty. It has been observed that distractor-present probes are associated with longer response latencies relative to distractor-absent probes (Milliken et al., 1999). Consequently, it follows that distractor-present probes are more difficult (because the interference of the probe distractor must be overcome for accurate target responding). Figure 2 (a) shows a representation of a more difficult version of the probe task. Here, responding is delayed until inhibition has accrued; therefore, negative priming is the result. Figure 2 (b) represents an easier version of the task. Here, responding takes place during (prime distractor/probe target) activation; therefore, the result is positive priming.

The aim of this study was to examine negative priming using four SOAs and two levels of difficulty within the same task. The purpose here was to measure the time course of the accrual and dissipation of negative priming in an attempt to assess whether negative priming covaries as a function of SOA and task difficulty. If inhibitory processes are an underlying cause of the negative priming effect as the cognitive inhibition model suggests, by measuring how the negative priming effect varies over time, one would also be measuring how cognitive inhibition varies over the time course of a processing event. Of primary concern in the following experiments was the temporal
Figure 2. Model of inhibition/activation across probe difficulty conditions for (a) difficult, and (b) easy conditions. The curved line represents processing of the prime distractor/probe target item (for a negative priming trial).
relationship between the onset of the prime display and the participant’s response to the probe.
EXPERIMENT 1

Experiment 1 utilized a negative priming lexical-decision task using four stimulus onset asynchronies (SOAs) to map a potential parametric function of negative priming. Using Stroop stimuli, Laplante et al. (1992) found that inhibition takes a matter of milliseconds to build to its maximum. Yee (1991) examined negative priming in a lexical decision task in which participants were instructed to categorize a geometric shape (i.e., a trapezoid or rectangle) while ignoring distractor words or nonwords that appeared on the screen above and below the shape. When a prime distractor item was subsequently presented in the probe trial, participants were expected to respond more slowly to the item as a word or a nonword than if the item had been presented in a control trial. In Yee’s study, positive priming was obtained for a 500 ms SOA, whereas negative priming was obtained for a 600 ms SOA.

Because previous research has revealed that the time course under which negative priming is obtained varies from task to task, Experiment 1 was chosen to provide a straightforward exploration of the time course under which negative priming can be found with the particular task chosen for this study. See the appendix for a more thorough discussion of the selection of experimental parameters used in the present study. This experiment attempted to replicate the negative priming effect and to observe its magnitude (if any) over several SOAs between the prime and probe displays. The range of SOAs chosen for this study were based on Yee’s (1991) finding of positive priming at 500 ms SOA and negative priming at 600 ms SOA. Because the type of response the participant was making in the present study is similar to that of Yee’s study, the critical
SOAs from her study were chosen along with a shorter (400 ms) and a longer (700 ms) SOA in order to widen the window in which any effects of cognitive inhibition might be observed.

In addition to reaction time data and error rates, each participant was administered the Cognitive Failures Questionnaire (Broadbent, Cooper, Fitzgerald, & Parkes, 1982). The CFQ was used as an index of general failures of attention. The questionnaire is scored, with a possible 100 indicating maximum reported failures of attention, and 0 indicating no reported failures of attention. Tipper and Baylis (1987) compared participant’s CFQ scores with performance on a negative priming task. They found that participants who scored low in cognitive failures exhibited negative priming (in repeated item trials) whereas those who scored high in cognitive failures failed to show negative priming. These results support the hypothesis that those who show negative priming are better inhibitors (because they seem to be inhibiting the repeated item identities) compared with those who do not show negative priming. If both the CFQ and the negative priming task were measuring the same type of inhibitory ability, then those who did well on the lexical decision task were expected to report fewer cognitive failures. This would add to the convergent validity of both the CFQ and the negative priming task as measures of cognitive inhibitory ability.

**Method**

**Participants**

Fifty-two undergraduate university students participated in exchange for course credit. All participants were right-handed native English speakers, who were free from
any reading disabilities and had normal or corrected to normal vision. Approximately two thirds of the participants were female.

Materials

A Power Mac 5400/120 computer controlled stimulus presentation and data collection. The “1” and “3” keys on the computer number pad were used for participants’ lexical decision responses. The “1” key was used for “non-word” responses and the “3” key was used for “word” responses. The Cognitive Failures Questionnaire (Broadbent et al., 1982) was given to each participant at the completion of the computer portion of the study.

Stimuli

Stimulus items were comprised of pairs of red and blue word or nonword items on a white background screen. Presentation of item pairs was centered on the computer screen with one item above the other in the vertical direction and the letter of one item offset in the horizontal direction as well. Word items were common 3-6 letter words used in the English language. Nonword items were derived from common English words in which a letter was removed and replaced by another letter, rendering the item a nonword. All nonwords, following rules of English, were easily pronounceable and did not sound like another actual English word (for example, “duc” which sounds like “duck” would not be used). An example of a nonword item would be “frel” (derived from free). Nonwords were also 3 to 6 letters long each.

Stimulus items were counterbalanced such that both red and blue items appeared as words or nonwords, in the upper or lower, and left or right positions an equal number of times for each participant. Red and blue items both appeared 50% of the time in
negative priming trials and 50% of the time in control trials for each participant. Each particular item appeared in only one trial to each participant. Number of letters in all stimulus items was also equated across all types of trials (negative priming versus control, and word versus non-word as the correct answer for both prime and probe trials). Each prime-probe trial pair consisted of items of all the same letter length.

All stimulus displays were centered on the computer monitor. Participants sat approximately 100 cm from the screen and stimulus letters were approximately .72 degrees of visual angle high and .29 degrees wide (with .40 degrees of visual angle space between letters). Stimulus items were backwards pattern-masked using a display consisting of random black lines.

Procedure

Participants were tested individually in a quiet room, seated facing the computer monitor. Participants were instructed to pay close attention to the items that were flashed on the monitor. A series of 96 prime-probe trial pairs was presented to each participant during the experiment. Half of the trials were repeated item trials and half were control trials. A prime trial consisted of a blank screen, followed by a fixation point, then a target item presented in red type along with a distractor item presented in blue type. Participants were instructed to pay attention to the red target items and to ignore the blue distractor items. Following presentation of the prime display, a backwards pattern mask composed of random black lines was presented. Masking the prime stimulus was done in order to reduce the likelihood that participants would become aware of the prime distractor identity. See the appendix for a brief discussion on the use of a prime pattern mask. Following presentation of the mask, a brief blank screen interval was followed by the
probe trial. The probe display was comprised of another target-distractor pair of items, one red, one blue, presented in the same fashion as that of the prime display. The participant’s task was to make a lexical decision on the probe target item, (i.e., if the probe target was a word, they were instructed to press the “3” key, if the probe target was a nonword, they were instructed to press the “1” key). The probe presentation was followed by another blank screen interval until the next prime-probe pair was presented.

Control trials were comprised of unrelated target and distractor items on both the prime and probe trials. Negative priming trials were comprised of prime distractor items reappearing as probe target items within the same prime-probe pair. Participants were instructed to respond as quickly and accurately as possible. For the stimulus presentation time sequence, see Figure 3.

SOAs were varied between-subjects such that each participant received an SOA (time between the onset of the prime and probe displays) of either 400, 500, 600, or 700 ms for all trials. Upon completion of the computer portion of the study, each participant was given the Cognitive Failures Questionnaire (Broadbent et al., 1982) and then debriefed.

Results

Reaction times (RTs) and errors associated with the lexical decision of the probe target were recorded and averages were calculated. Both RTs and error rates were analyzed using a mixed design ANOVA in which SOA (400, 500, 600, or 700 ms) was the between-subjects factor and trial type (control versus negative priming) was the within-subjects factor. All analyses were conducted with an alpha level of .05 as the
Figure 3. Stimulus sequence and durations.
criterion for statistical significance. Only RT data for trials with correct responses were included in analyses. Of particular interest was how RT varied with SOA.

Analysis of reaction time scores yielded neither significant effects of trial type, SOA, nor a trial type x SOA interaction (for means and standard deviations see Table 1). However, some SOAs were predicted a priori to yield more negative priming than others, and visual inspection of the data (see Figure 4) suggested a possible disordinal interaction between the 400 and 600 ms SOA conditions. When these two conditions were compared, a significant trial type x SOA interaction was found, \( F(1, 24) = 4.33, p < .05 \). The 400 ms SOA group produced faster RTs for control trials (relative to negative priming trials), whereas the 600 ms SOA group produced faster RTs for negative priming trials (relative to control trials). The 400 ms SOA group experienced negative priming overall, in contrast to the 600 ms group who experienced overall priming (i.e., faster response to repeated item trials relative to control trials).

Because individual differences between participants’ performance was expected, difference scores for RTs were calculated. Difference scores (sometimes referred to in the literature as negative priming scores) are obtained by subtracting each participants’ mean control trial RT from their mean negative priming trial RT. Difference scores provide a way to control for the fact that some participants are overall faster in their performance than others. These scores were examined in a between subjects ANOVA with SOA (400, 500, 600 or 700 ms) as the factor. No significant effects of SOA were found for difference score RTs (see Table 2 for difference score means and standard deviations). See Figure 5 for a graphical representation of difference scores across SOA conditions.
Table 1

Mean Reaction Times and Error Rates For Experiment 1*

<table>
<thead>
<tr>
<th></th>
<th>SOA</th>
<th>Reaction Time</th>
<th>Errors</th>
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<tbody>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ms</td>
<td></td>
<td>814.12 (153.42)</td>
<td>2.23 (1.88)</td>
</tr>
<tr>
<td>500 ms</td>
<td></td>
<td>833.37 (195.22)</td>
<td>3.38 (2.53)</td>
</tr>
<tr>
<td>600 ms</td>
<td></td>
<td>805.17 (146.37)</td>
<td>1.69 (1.75)</td>
</tr>
<tr>
<td>700 ms</td>
<td></td>
<td>841.05 (125.35)</td>
<td>2.85 (1.77)</td>
</tr>
<tr>
<td><strong>Negative Priming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ms</td>
<td></td>
<td>828.18 (180.92)</td>
<td>2.77 (2.20)</td>
</tr>
<tr>
<td>500 ms</td>
<td></td>
<td>833.01 (236.33)</td>
<td>2.69 (1.75)</td>
</tr>
<tr>
<td>600 ms</td>
<td></td>
<td>771.70 (136.67)</td>
<td>1.54 (1.27)</td>
</tr>
<tr>
<td>700 ms</td>
<td></td>
<td>825.98 (124.99)</td>
<td>3.77 (2.80)</td>
</tr>
</tbody>
</table>

*Reaction times are in milliseconds. Standard deviations are in parentheses.
Figure 4. Experiment 1 RT for control and negative priming trials across SOA.
Table 2

Mean Reaction Time Difference Scores for Experiment 1*

<table>
<thead>
<tr>
<th>SOA</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 ms</td>
<td>14.06 (61.54)</td>
</tr>
<tr>
<td>500 ms</td>
<td>-.36 (86.80)</td>
</tr>
<tr>
<td>600 ms</td>
<td>-33.47 (54.72)</td>
</tr>
<tr>
<td>700 ms</td>
<td>-15.07 (63.27)</td>
</tr>
</tbody>
</table>

*Positive difference scores indicate negative priming; negative scores indicate positive priming. Standard deviations of difference scores are in parentheses.
Figure 5. Experiment 1 RT difference scores (negative priming RT minus control RT) across SOA.
Examination of response errors revealed neither significant effects of trial type, SOA, nor a trial type x SOA interaction (see Table 1 for error rate means and standard deviations). However, the overall effect of SOA on error rates approached conventional significance, $F(3, 48) = 2.31, \ p < .10$. Post-hoc Tukey tests revealed that the greatest difference in error rates occurred between the 600 and 700 ms SOA conditions (1.61 versus 3.31 errors, respectively).

Participants’ scores on the Cognitive Failures Questionnaire (Broadbent et al., 1982) were also compared with RT difference scores. Scores on the CFQ ranged from 24 to 73, with a median of 40 (out of a possible 100). A non-significant correlation was obtained. However, when only the participants who scored in the highest third on the CFQ (which corresponded to those individuals with CFQ scores greater than 45) were examined in the analysis, a significant positive correlation was obtained between CFQ score and RT difference score, $r (16) = .519, \ p < .05$. This finding suggests that participants who self-reported the most cognitive errors on the CFQ were also slower on negative priming (relative to control) trials. All other correlations involving CFQ scores were non-significant.

**Discussion**

Experimental results revealed that overall negative priming did not occur on repeated item trials. That is, across all SOAs, negative priming trials were not universally slower than control trials. Analyses did reveal fluctuations between negative priming and positive priming (faster RTs to repeated item trials relative to control trials) across SOA. Negative priming was obtained for the 400 ms SOA group in contrast to the positive priming obtained for the 600 ms SOA group. The cognitive inhibition model could
account for these findings, in that all stimulus items may have been activated at a point prior to 400 ms, repeated items in negative priming trials could then have been inhibited around 400 ms (as exemplified by the overall slower RT performance on negative priming trials relative to control trials at this SOA), and then inhibition could have run its course by 600 ms (when repeated items were primed relative to control items). However, because there were no significant differences between negative priming and control trials at 500 and 700 ms, there was no overall negative priming effect for RTs. Other alternatives are that this pattern of results simply reflects random variation. A large amount of variability of RT scores was obtained in this experiment (see Table 1 for the standard deviations). An overall negative priming effect may not have been obtained due to the large variability of scores in the sample that obscured measurement of the predicted effect.

Error analyses revealed no significant differences between trial types or across SOA. The only near-significant error comparison suggested that participants made the fewest errors at 600 ms and the most at 700 ms. Of the four SOAs tested, the 600 ms SOA was associated with the most priming. If the 600 ms SOA was associated with the window of time in which inhibition has worn off, and residual activation of all items was still in force, a combination of faster RTs and lower error rates at this SOA converge to support the hypothesis that priming may have occurred following an inhibitory period for repeated stimulus items. Both RTs and error rates increased for 700 ms (although not significantly so) suggesting that the priming effect wears off between 600 and 700 ms.

In addition to RT data and error rates, each participant was administered the Cognitive Failures Questionnaire (Broadbent et al., 1982). Previously, Tipper and Baylis
(1987) found that CFQ score was related to whether or not negative priming was obtained from participants in a reaction time categorical naming study.

It was anticipated that in the current study, participants scoring highest on the questionnaire (i.e., exhibiting the most cognitive failures) would exhibit lower negative priming scores. The logic behind this expectation is that those who tend to experience more cognitive failures are thought to be poor cognitive inhibitors. Poor cognitive inhibitors would (according to the cognitive inhibition model for negative priming) inhibit prime distractors less effectively and hence have less inhibition to overcome when a subsequent response to the probe target (when identical to the prime distractor) is demanded. Relatively good cognitive inhibitors (those who experience relatively few cognitive failures) would be expected to show higher negative priming scores, because these participants were thought to effectively inhibit the prime distractor and hence have more inhibition to overcome when a subsequent response to the probe target (when identical to the prime distractor) was demanded. Experiment 1 revealed no significant overall correlation between negative priming and CFQ score. However, when participants were split into good, intermediate and poor inhibitors (according to their score on the CFQ), only the “poor” inhibitors’ CFQ scores correlated significantly with their RT difference scores. Of those “poor” inhibitors, those who self-reported the most cognitive errors actually experienced more negative priming relative to those reporting fewer cognitive errors. This finding runs contrary to expectations. One possible explanation is that the CFQ is not measuring the same type of inhibitory ability that produces a negative priming effect. The CFQ is a self-report scale, subject to possible inaccuracies in reporting. Those participants with poor meta-cognitive ability may have underestimated
their rate of cognitive failures when filling out the questionnaire. Another possible explanation is that the current study did not find a strong and consistent negative priming effect with which to correlate CFQ scores.
EXPERIMENT 2

One of the aims of this investigation was to provide a direct comparison (within the same laboratory using the same task) between difficult and easy (probe interference-present versus probe interference-absent) response conditions. The purpose of this comparison was to investigate how the time course of the negative priming effect may change due to only a slight difference in the timing of the participants’ responses. The objective of Experiment 2 was to determine whether making the task easier would affect the time course of negative priming. If interference is removed on the probe trial (by presenting only one item on the screen for the probe display, as opposed to two), thereby making the probe task easier, the time course of negative priming may be altered. In Experiment 1, negative priming was obtained only for the 400 ms SOA condition. It was hypothesized that making the probe response task easier results in reaction times that are faster. These faster reaction times suggest that participants would be more likely to make their response selection during the period when negative priming is at its peak. In other words, negative priming obtained from an easier 500 or 600 SOA condition should resemble that of a more difficult 400 SOA condition (because more difficult task demands delay participants’ responses to the probe by a few extra milliseconds). If this was the case, it was expected that the parametric function for negative priming obtained from Experiment 2 would be altered relative to that of Experiment 1. On the other hand, if a parametric function emerged which was basically identical to that of Experiment 1, this would suggest that either an inadequate selection of SOAs was employed for Experiment 2, or that the rise and fall of inhibitory processing was not responsible for the
rise and fall over time of the negative priming effect. But, if the window of maximal negative priming (to the prime distractor) could have been moved simply by changing the time course of processing events (by making the task easier), it would support the hypothesis that, holding overall type of processing task constant, the difficulty of the task would influence the negative priming effect via the interaction of maximal inhibitory processing with the cognitive processing required by the task.

Method

Fifty-two participants (who did not participate in Experiment 1) were tested. Procedures for Experiment 2 were identical to those of Experiment 1, except that probe trials in Experiment 2 involved presentation of a target item without an accompanying distractor.

Results

Reaction times (RTs) and errors associated with the lexical decision of the probe target were recorded and averages were calculated. RTs and error rates were analyzed using a mixed design ANOVA in which SOA (400, 500, 600, or 700 ms) was the between-subjects factor, and trial type (control versus negative priming) was the within-subjects factor. Just as with the first experiment, of particular interest was how RT varied with SOA.

Analysis of RT scores revealed neither significant effects of trial, type, SOA, nor trial type x SOA interaction. Visual inspection of the data suggested no significant effects of trial type for any SOA (see Figure 6). RT difference scores were calculated (as in
Figure 6. Experiment 2 RTs for control and negative priming trials across SOA.
Experiment 1) and revealed no significant differences across SOA. See Table 3 for RT means and standard deviations, Table 4 for RT difference scores, and Figure 7 for a graphical representation of Experiment 2 RT difference scores.

Error rate analyses revealed a main effect of trial type, $F(1, 48) = 5.82, p < .05$. Participants made an average of 2.81 errors on negative priming trials and 2.06 errors on control trials (see Table 4 for error rate means and standard deviations). Analyses revealed neither significant differences in error rates across SOA, nor a significant trial type x SOA interaction.

Participants’ scores on the CFQ (Broadbent et al., 1982) were also compared with RT scores. Scores on the CFQ ranged from 18 to 78, with a median of 41 (out of a possible 100). A significant positive correlation between CFQ score and RT on negative priming trials was found, $r(52) = .285, p < .05$. Those participants who scored higher on the CFQ were also slower to respond on negative priming trials (relative to those who scored lower on the CFQ). All other correlations involving CFQ scores were not significant.

**Discussion**

As in Experiment 1, it was expected that, overall, negative priming trials in Experiment 2 would result in longer RTs (and possibly larger error rates) compared with those of the control trials. This was expected to be due, if the cognitive inhibition model is correct, to the time necessary for the prime distractor item to have been released from inhibition in order to have been processed to the extent necessary for the participant to make the lexical decision on that item.
Table 3

Mean Reaction Times and Error Rates For Experiment 2*

<table>
<thead>
<tr>
<th></th>
<th>SOA</th>
<th>Reaction Time</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ms</td>
<td>757.13 (142.99)</td>
<td>1.92 (2.14)</td>
<td></td>
</tr>
<tr>
<td>500 ms</td>
<td>653.64 (94.63)</td>
<td>1.92 (2.02)</td>
<td></td>
</tr>
<tr>
<td>600 ms</td>
<td>681.52 (135.19)</td>
<td>1.54 (1.57)</td>
<td></td>
</tr>
<tr>
<td>700 ms</td>
<td>735.69 (148.88)</td>
<td>2.85 (2.73)</td>
<td></td>
</tr>
<tr>
<td><strong>Negative Priming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ms</td>
<td>758.08 (135.08)</td>
<td>2.08 (1.50)</td>
<td></td>
</tr>
<tr>
<td>500 ms</td>
<td>654.40 (107.63)</td>
<td>3.15 (1.77)</td>
<td></td>
</tr>
<tr>
<td>600 ms</td>
<td>668.51 (135.42)</td>
<td>3.15 (1.77)</td>
<td></td>
</tr>
<tr>
<td>700 ms</td>
<td>748.91 (142.10)</td>
<td>2.85 (2.30)</td>
<td></td>
</tr>
</tbody>
</table>

*Reaction times are in milliseconds. Standard deviations are in parentheses.
Table 4
Mean Reaction Time Difference Scores for Experiment 2*

<table>
<thead>
<tr>
<th>SOA</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 ms</td>
<td>0.95 (49.72)</td>
</tr>
<tr>
<td>500 ms</td>
<td>0.76 (33.71)</td>
</tr>
<tr>
<td>600 ms</td>
<td>-13.01 (42.36)</td>
</tr>
<tr>
<td>700 ms</td>
<td>13.22 (58.65)</td>
</tr>
</tbody>
</table>

* Positive difference scores indicate negative priming; negative scores indicate positive priming. Standard deviations of difference scores are in parentheses.
Figure 7. Experiment 2 RT difference scores (negative priming RT minus control RT) across SOA.
The negative priming scores obtained were expected to vary across SOA for each trial type. Following the cognitive inhibition model, longer RTs were hypothesized to result from the trials in which the response to the probe target was made during the window of maximal cognitive inhibition for the prime distractor. The same general pattern of results was expected for Experiment 2 as for Experiment 1 with the following exception: because the task was easier in Experiment 2, the shortest SOA would produce priming rather than negative priming. This was anticipated because making the task easier should help participants respond more quickly. If the response to the probe task was made during the period of initial activation of all items, then facilitation rather than inhibition of prime distractors would result.

Analysis of the results for Experiment 2 revealed that negative priming did not occur on repeated item trials. There were no significant main effects or interactions in any of the RT data for Experiment 2. These findings contradict the prediction that negative priming would occur on the repeated item trials and that an identifiable pattern would emerge across the SOAs.

Examination of errors revealed a significant main effect of trial type. Overall, more errors were made on negative priming trials than on control trials. This finding is consistent with predictions that either slower RTs or larger error rates (or both) would occur for negative priming trials than for control trials. Therefore, there is some evidence that the negative priming contingency influenced performance consistent with the cognitive inhibition interpretation.

Participants’ scores on the Cognitive Failures Questionnaire (Broadbent et al., 1982) were also analyzed. It was expected that participants scoring highest on the
questionnaire would exhibit lower negative priming scores. This general pattern was not found. However, analysis of the data revealed that CFQ scores were significantly correlated with RT on negative priming trials. Those participants who reported more cognitive failures were slower to respond on negative priming trials (relative to those who reported fewer cognitive failures). This finding is consistent with the hypothesis that those who make more cognitive failures in general would tend to be those who produce the slowest RTs in general.
COMPARISON OF EXPERIMENTS 1 AND 2

One of the potential problems with the negative priming literature is the lack of consistency across studies in terms of the conditions under which negative priming is found. One of the aims of this investigation was to provide a comparison (within the same laboratory using the same task) between difficult and easy (probe interference-present versus probe interference-absent) response conditions. The purpose of this comparison was to investigate how the time course of the negative priming effect may change due to only a slight difference in the timing of the participants’ responses (i.e., if the task were easier, participants would be able to make their lexical decision to the target faster).

To examine this issue, analysis of variance was used to compare Experiment 1 and Experiment 2 RT and error rate data. Separate RT and error rate mixed design ANOVAs were run in which trial type (negative priming versus control) was the within-subjects factor, and SOA (400, 500, 600 or 700 ms) and experiment (1 versus 2) were the between subjects factors. A significant main effect of experiment was found for RT data, \( F(1, 96) = 14.97, \ p < .0001 \). Participants’ mean RTs in Experiment 1 were significantly slower \( (M=819.07 \text{ ms}) \) than for Experiment 2 \( (M=707.24 \text{ ms}) \). No other significant main effects or interactions were found between experiments for the RT data (see Figures 8 & 9). A separate ANOVA revealed neither significant main effects nor any significant interactions between experiments for the error rate data.

A comparison of RT data from Experiments 1 and 2 reveal that the non-interference condition (Experiment 2) produced significantly faster RTs than the
Figure 8. Experiment 1 and 2 RTs for control and negative priming trials across SOA.
Figure 9. Experiment 1 and 2 RT difference scores (negative priming RT minus control RT) across SOA.
presumably more difficult interference condition (Experiment 1). This finding supports
the hypothesis that, when there was no interference on the probe trial, the task was easier,
and the participant responded more quickly (compared with the interference-present
probe trials of Experiment 1). However, the overall predicted pattern of RTs across SOAs
was not obtained. It was hypothesized that negative priming would be obtained, that the
pattern of negative priming would vary across SOA, and that this pattern would be
different for the two experiments. Because significant negative priming effects were not
obtained across the two experiments, comparisons of the varying pattern of negative
priming across SOAs cannot be made.
GENERAL DISCUSSION AND CONCLUSIONS

The experiments reported here attempted to support the cognitive inhibition hypothesis using a negative priming lexical decision task across four SOAs and two degrees of probe difficulty. An application of the cognitive inhibition model to a negative priming situation was expected to reveal differences in the time-course of the negative priming effect which would be suggestive of the development (accrual, maximization, and then dissipation) of cognitive inhibition. Of critical importance to the present study’s hypothesis is the suggestion that it is the temporal relationship between the onset of the prime display and the participant’s response to the probe stimulus that is responsible for many of the findings in the negative priming research literature. An application of the cognitive inhibition model to a negative priming study predicts that at the shortest SOAs, priming of repeated items (i.e., distractors from the prime display that subsequently become targets on the probe display) would occur. Negative priming would occur at the slightly longer SOAs because inhibition has had time to accrue. Finally, a decrease or absence of inhibitory effect would occur at even longer SOAs due to the dissipation of inhibition. This pattern of results was expected to be altered for the interference-absent situation in Experiment 2. Again, an application of the cognitive inhibition model would lead one to predict that if the probe task is easier, probe response latency would be shorter, hence the changing degrees of negative priming over time for these easier trials would resemble negative priming at shorter SOAs for the more difficult, interference-present situation presented in Experiment 1. In other words, there are two temporal variables at work, the SOA, which is determined by the experimenter, and the time it takes for the
participant to make the response to the probe. These two intervals of time occur immediately one after the other (because the participant can only begin to process the probe stimulus after the SOA is over and the probe display is presented).

The predicted pattern of negative priming across SOA and across interference conditions was not obtained in Experiments 1 or 2. Some of the expected results, however, were obtained. For example, longer mean response latencies for the more difficult Experiment 1 trials relative to the easier Experiment 2 trials were obtained. This indicated that inclusion of a distractor on the probe trial made response selection on the probe more difficult. This also indicated that the presence or absence of a probe distractor was effective as a method of altering task difficulty.

One possibility for the lack of an overall negative priming effect is that cognitive inhibition is not responsible for negative priming. Alternative models that emphasize memory retrieval processes have also been used to account for the negative priming effect. For example, one of the most widely cited non-inhibition models is episodic retrieval (Neill, 1997; Neill et al., 1992). The episodic retrieval model suggests a process whereby probe stimulus presentation may or may not evoke retrieval of the prime processing episode depending on a number of factors. These factors include similarity of prime and probe stimulus items and the temporal relationship between prime and probe presentation (Neill et al., 1992).

Another possibility for the failure to find an overall negative priming effect, is that some sort of inhibitory process is responsible for negative priming, but not in the manner hypothesized in the current study. Cognitive inhibition is a model that proposes the general rise of and fall of inhibitory effects over time as cognitive items are
processed. The model describes an initial brief activation for target as well as distractor items (although the distractor items are not activated to the level where the participant has conscious awareness of their identities). Next, inhibition accrues over time for the non-selected item as the target is further activated. Subsequently, inhibitory effects dissipate and disappear after sufficient time has elapsed. The model may be too simplistic and not take account of the possibility that activation of prime distractors may occur at any time during the processing episode. The cognitive inhibition model may also not place enough emphasis on backward-acting memorial processes. Hybrid models involving both cognitive inhibition and memory retrieval processes may provide a better account of negative priming than either process alone (Tipper, 2001).

Another possibility for the lack of overall negative priming effect, is that the cognitive inhibition model is accurate, but that methodological problems prevented the expected pattern of results to be found. The condition associated with the most negative priming in Experiment 1 was the shortest SOA tested (400 ms). Because there was no previous research that utilized the exact same parameters as the current study, the selection of SOAs used here was based on a somewhat similar study by Yee (1991). Results obtained from the present study indicate that a more judicious range of SOAs, including some which are shorter than 400 ms might better capture any negative priming effects that went unmeasured in this study.

If the negative priming effect had been reliably obtained, and if the pattern of negative priming across SOA and across interference conditions had been as hypothesized, it would have lent support to the cognitive inhibition account of negative priming. It would also have helped to account for some of the inconsistencies in the
presence and degree of, the negative priming effect in a number of studies. In order to accomplish these goals, further investigation is needed. The complicated nature of cognition makes it difficult to single out one aspect of attentional processing when so many processes operate together. The specifics of stimulus properties or task demands in this area of research require a very controlled investigation as to the conditions under which negative priming is found to occur.
REFERENCES


APPENDIX

Experimental Methodology Issues

The negative priming effect is thought to be tenuous and sometimes difficult to replicate (Park & Kanwisher, 1996). For the present study, the experimental paradigm and details of methodology were carefully chosen in an attempt to avoid many of the problems inherent in this area of study.

A lexical decision task was chosen because lexical decision is thought to involve a deep level of cognitive processing of an object-based (semantic) nature. Previous research reveals that object-based and location-based negative priming may involve different cognitive mechanisms or processing systems (Connelly & Hasher, 1995; Kane et al., 1997; May et al., 1995). Location-based negative priming is worthy of study, but not of primary focus in the current investigation. Negative priming has been obtained with past lexical decision studies (Fox, 1994; Yee, 1991). The lexical decision paradigm also affords the probe-interference present versus absent manipulation utilized in Experiment 2, and allows use of large sets of non-repeating stimulus items (see below).

Some previous studies used small sets (i.e., 4 or 6) of stimulus items that were repeated numerous times over the course of an experiment. For example, Milliken and Joordens (1996) used the same four stimulus word items repeated throughout their study. It has been suggested (Johnston & Dark, 1986; Yee, 1991) that the use of small sets of repeated items may unintentionally bias the participant towards priming (in negative priming trials). In order to avoid this bias, a relatively large set of non-repeated words
and nonwords were utilized in the present study such that no item was presented twice to a participant.

Negative priming studies may or may not require participants to respond to the prime target stimulus. Yee (1991) has pointed out that a paradigm, which does not require the participant to make an overt response to the prime target, may reduce unwanted reaction time variability. In typical studies in which an overt response (i.e., a key press, or verbal response) is required immediately after presentation of the prime display, the prime-to-probe SOA becomes variable. Because the onset of the probe display is usually contingent upon response to the prime, the onset of the probe will vary with participants’ speed of response to the prime. Because the present study involves an attempt to carefully control and measure probe reaction time response across SOAs, no overt prime responses were requested of the participants. Participants were told, however, to pay close attention to the prime targets and to read them silently to themselves.

Finally, one last methodological issue applicable to the current study involved the decision to present a pattern mask immediately after presentation of the prime display. Previous research suggests mixed effects resulting from use of a pattern mask (i.e., display comprised of scrambled black lines) following the prime display. Some researchers have found an absence of negative priming when prime displays were masked (Allport et al., 1985), whereas others obtained the expected negative priming effect when prime display masking was utilized (Tipper, 1985; Tipper et al., 1991; Yee, 1991). Tipper (1985) has suggested that use of a pattern mask serves to reduce the possibility of a participant switching attention to the distractor item after selection of the prime target has been made. According to Hasher, Stoltzfus, Zacks and Rympa (1991), awareness of the
negative priming contingency present in experimental trials may produce priming rather than negative priming as would normally be expected. Based on these findings, a prime display pattern mask was used in the current study in order to help reduce the likelihood of the participants becoming aware of the prime distractor identity and notice the negative priming contingency present in the negative priming trials.