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The Role of Perceptual Load in Negative Priming

Nilli Lavie
University College London

Elaine Fox
University of Essex

Negative priming (NP) effects from irrelevant distractors were assessed as a function of perceptual load in the processing of prime targets. Participants searched for a target letter among a varying number of nontarget letters in the center of the display and ignored an irrelevant peripheral distractor. NP from this distractor was found to depend on the relevant search set size, decreasing as this set size was increased. The authors conclude that exhausting attention in relevant processing reduces irrelevant processing (e.g., N. Lavie, 1995), leaving less distractor processing to produce NP. This conclusion is consistent with recent reactive inhibition views for NP (e.g., G. Houghton, S. P. Tipper, B. Weaver, & D. I. Shore, 1996).

Selective attention involves dedicating one's mind to the processing of goal-relevant information while attempting to ignore irrelevant and potentially distracting information. Although focusing attention on relevant information and attempting to avoid distraction from irrelevant information may appear unified in our personal experience, theories of attention typically have emphasized either one function of attention or the other.

The importance of allocating attention to relevant information has been discussed in capacity approaches (e.g., Kahneman, 1973; Navon & Gopher, 1979). In this view, attention is described as a mental resource that is essential for information processing, exists in a limited amount, and can be allocated flexibly to various sources of information (e.g., Gopher, 1992). The main function of attention in these theories is to facilitate processing of relevant information in a manner that may be analogous to how increased blood flow can permit high levels of neural activity in brain areas that receive it.

The capacity approach has been primarily addressed to divided-attention studies. In contrast, the ability to ignore irrelevant information has been discussed typically within a theoretical framework that emphasizes the selective aspects of attention. Within this selective attention framework, there seems to be a general agreement that irrelevant information is processed differently from relevant information. However, there is little agreement on whether withholding attention can result in the exclusion of irrelevant information from perception (e.g., the "early selection" view, see Treisman, 1969) or whether selective attention can affect only later processes, such as memory or responses (as in late selection views, e.g., Duncan, 1980; see Lavie & Tsal, 1994, for a recent review of the early-vs.-late selection debate). More recently, some progress has been made in the study of the actual mechanisms of ignoring, and an active *inhibition* view of selective attention has been proposed (e.g., Neill, 1977; Tipper, 1985; see a recent review in Fox, 1995). In this view, perceptual processing proceeds for both relevant and irrelevant information (as in late selection accounts), and attention is therefore required for suppressing responses to processed, yet irrelevant, information. The phenomenon of *negative priming* (NP), which is the slowing down of responses to items that were previously ignored, has been taken as evidence for such an active inhibition mechanism (e.g., Tipper, 1985; Tipper & Milliken, 1996; possible noninhibitory accounts of NP are considered later).

Mechanisms of active inhibition would provide one clear means of response selection in situations of late selection, when both relevant and irrelevant information are perceived. However, the existence of such an active inhibition mechanism would not preclude other mechanisms of selection, and in particular, it remains possible that irrelevant information can at least in some cases be excluded from perception as well as from responses (i.e., as in early selection accounts). Thus, although the theory of active inhibition provides an important mechanism for response selection in cases of unselective perception, it does not provide a resolution to the main issue of debate in selective attention studies, namely, whether irrelevant information can ever be excluded from perception as well as from responses. Given the ample evidence that selective attention can sometimes result in selective perception yet at other times in unselective perception, a hybrid model in which both modes of selection are possible may provide a better account of the diverse data than either a strict early- or a strict late-selection view alone.

Lavie (1995; Lavie & Tsal, 1994) recently proposed such a hybrid model (see Desimone & Duncan, 1995; Johnston & Heinz, 1978, for other hybrid models of selective attention), and in the present study we investigate the implications of this model for the possible mechanisms of active inhibition. The model assumes that perception has limited capacity (such that perception is naturally selective in situations of high perceptual load that exceeds those capacity limits), but it also assumes that it is impossible to withhold perception for any information within the capacity limits (as

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Nilli Lavie, Department of Psychology, University College London, London, England; Elaine Fox, Department of Psychology, University of Essex, Essex, England.

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Correspondence concerning this article should be addressed to Nilli Lavie, Department of Psychology, University College London, Gower Street, London WC1E 6BT, England. Electronic mail may be sent to n.lavie@ucl.ac.uk.

in situations of low perceptual load). Early selection (i.e., selective perception) is predicted under conditions of high load in relevant perception that exhaust capacity; late selection is predicted in situations of low perceptual load in relevant processing that leave spare capacity for the processing of irrelevant information. Thus, in Lavie's model, selective attention can result in either selective perception (as in early selection) or unselective perception of irrelevant information (i.e., late selection), and whichever mode of selection occurs is determined by the perceptual load involved in relevant processing.

The "perceptual load" model received direct support from a series of experiments that directly manipulated perceptual load in relevant processing and measured irrelevant processing by examining flanker interference effects. Thus, Lavie (1995) demonstrated that increasing the number of items that were relevant for target perception or increasing the processing requirements for the same items led to reduced processing of irrelevant distractors. In addition, Lavie and Cox (1997) demonstrated that visual search load can determine the rejection of peripheral distractors that appear outside the search area. For example, efficient searches that allowed for target pop-out from among dissimilar nontargets led to inefficient rejection of irrelevant peripheral distractors, because the relevant load was low. On the other hand, inefficient searches with a steep search slope led to efficient rejection of irrelevant peripheral distractors, as long as more than four items were involved in the relevant search to exhaust capacity (For similar reports of capacity limits, see Fisher, 1982; Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, Burkell, Fisher, & Sears, 1994; and Yantis & Jones, 1991.)

In all of these experiments, selective processing was assessed by measuring response competition effects from irrelevant distractors (e.g., Eriksen & Eriksen, 1974). Thus, concurrent interference effects from distractors that were incompatible, compatible, or neutral with the target responses were taken as evidence for distractor processing, and the consistent finding of reduced interference effects under high versus low perceptual loads was taken as evidence for reduced distractor processing with higher loads.

What are the implications from these studies for the mechanisms of distractor inhibition associated with NP? In some active inhibition views of NP (e.g., Driver & Tipper, 1989), the finding of more selective processing with high versus low perceptual loads should lead us to expect greater inhibition with higher perceptual loads. If active inhibition serves as the primary means for selective processing, then the reduced interference from distractors as a result of higher perceptual load (e.g., Lavie, 1995; Lavie & Cox, 1997) may not necessarily reflect less distractor processing as Lavie previously claimed but rather more inhibition applied to irrelevant distractors (see Driver & Tipper, 1989, for related claims about NP). Thus, in this active inhibition view, greater NP effects are predicted in high versus low perceptual loads reflecting the greater suppression of distractors (and hence reduced response competition from incongruent distractors) with higher loads.

A different prediction for NP arises from our proposed role for perceptual load in producing selective perception. If load in relevant processing determines the extent of irrelevant processing, then greater distractor inhibition will be required under situations of *low* rather than high perceptual loads, because there will be more distractor processing with low loads, which will then require more inhibition to be suppressed. Thus, from the perceptual load hypothesis, more NP is predicted under low rather than high loads. Note that this prediction is consistent with a recent suggestion that inhibition may be a reactive process such that greater distractor activation requires more inhibition for its suppression (e.g., Fox, 1994, 1998; Houghton, Tipper, Weaver, & Shore, 1996; Malley & Strayer, 1995; Neil, Valdes, & Terry, 1995). If the greater interference Lavie (1995; Lavie & Cox, 1997) found from irrelevant distractors under low perceptual loads indicated greater activation of those distractors, as we claim, then more NP is predicted in low versus high loads also from such reactive inhibition views of NP.

However, it is important to emphasize that all previous inhibition views of NP have suggested mechanisms of active (or reactive) inhibition in responses to distractors that are invariably considered to be fully perceived, and they have thus emphasized active ignoring as an alternative to more "passive" views of selection in which the distractor may sometimes not be perceived at all (e.g., Neisser, 1976). By contrast, in the present approach we combine both active *and* passive means of ignoring irrelevant distractors under the same model that allows us to predict which mode of selection should occur on the basis of the level of perceptual load involved in the relevant processing. Thus, we argue that perceptual load in the processing of relevant information plays a major role in determining the processes of active ignoring typically associated with NP. Situations of low perceptual load that result in late selection will require active mechanisms of ignoring (e.g., inhibition of response tendencies to irrelevant distractors) and thus lead to NP. By contrast, situations of high perceptual load, which exhaust capacity in relevant processing, will lead to reduced perception of irrelevant distractors, thus leaving "less of a distractor" to inhibit. This should then result in reduced NP. The predicted reduction in NP effects in high-load situations reveals, in our view, the operation of an earlier and more passive mode of selection.

Previous Load Effects in NP

Our prediction for the role of perceptual load in NP receives some support from previous studies. Indeed, most of the previous NP effects were typically obtained in situations of very low perceptual load, with displays of just one target and one distractor (see Lavie & Tsal, 1994, for a more detailed analysis). A few studies have recently examined the effect of increasing the number of distractors on NP. Thus, Neumann and his colleagues (e.g., Neumann, Cherau, Hood, & Steinnagel, 1993; Neumann & DeSchepper, 1992) found that NP effects were reduced as the number of distractors was increased from 1 to 3 (see also Houghton et al., 1996). These findings generally support our perceptual load hypothesis, because the greater perceptual load with more items should reduce the available capacity for processing of each distractor and hence lead to reduced inhibition.

However, perceptual load was not the only factor that was varied with the number of distractors in these studies. For example, with more distractors the perceptual saliency and response association strength for each one of the distractors may be weakened. In such cases, weaker activation for each one of the distractors is expected (but for reasons other than perceptual load), and hence less inhibition is required for suppressing each distractor.[1] Thus, the reduced NP with more distractors cannot be attributed solely to increases in perceptual processing load. What is needed to directly test the perceptual load hypothesis is a manipulation of load in relevant processing, where the extra items are not mapped to any responses in the context of the experiment.

A recent study examined the role of working memory load in NP, without involving any change in the displays. Engle, Conway, Tuholski, and Shisler (1995) presented a word after every pair of prime-probe trials and examined recall for these words after five successive prime-probe trials. NP was then compared between trials in which there had been 0–4 words to remember. The results showed reduced NP for any trials that involved more than one word to remember. Although these results demonstrate that working memory capacity is important for NP, it is not clear which component of NP is affected by it. For example, in Engle et al.'s task, memory load could have affected processing in either the prime displays (which present the critical distractor) or the probe displays (which present the prime-distractor as their target), or both. Moreover, any process of memory retrieval that may be involved in NP (see Neill, Valdes, & Terry, 1992) seems likely to be affected by memory load. Thus, with greater memory load, reduced retrieval of the prime distractors during the processing of the probes, rather than reduced distractor inhibition in the prime, might lead to reduced NP. Nevertheless, the study by Engle et al. does provide a demonstration of the importance of working memory for mechanisms of NP.

In summary, previous studies varied either the number of distractors or the general working memory load in the task, and although their findings generally support a role for capacity limits in NP (but see Houghton et al., 1996, for a different account), they do not provide any direct test of our hypothesis, which predicts specifically that perceptual load in relevant processing in the prime display will determine negative priming effects from irrelevant prime distractors. The present experiments were designed to test this hypothesis.

General Method

In these experiments, we manipulated perceptual load in the relevant target processing by varying the relevant set size for the prime target (as in Lavie, 1995). A target letter appeared in one of six positions arranged in a row (Experiments 1, 2, and 4) or a circle (Experiment 3) at the center of the prime display, and load was manipulated through the five nontarget positions, which were either empty (i.e., low perceptual load) or occupied with five nontarget items (high perceptual load). The nontarget items were not associated with any response in the present task, and in this way they served to increase the load in the process of target search (see also Lavie & Cox, 1997) without reducing the strength of association with response for the single irrelevant distractor (cf. Houghton et al., 1996; Neumann & DeSchepper, 1992; Neumann et al., 1993). One irrelevant distractor appeared in all displays, at a remote position in the periphery, and the participants were told to ignore this distractor. Any NP effects from the irrelevant distractor were assessed by examining responses to a subsequent probe display, comparing trials that involved repetition of the prime distractor as the probe target (ignored repetition, Condition IR), and trials that did not involve any item repetition (control, Condition C, see Figure 1). We predicted that NP effects (i.e., slowing down of responses in the IR vs. C conditions) would be found under low perceptual load in the prime display and would be reduced or eliminated with higher perceptual load.

A condition of target repetition between the prime and probe displays (attended repetition, Condition AR) was also included in our design, although we did not derive any prediction for AR from our perceptual load hypothesis.[2] This AR condition was included because recent studies (e.g., Fox, 2000; Kane, May, Hasher, Rahhal, & Stoltzfus, 1997) have found that NP effects are generally larger when a proportion of trials included repetition of the target item across prime and probe displays. Thus, we sought to investigate the influence of perceptual load on NP under conditions that should allow for a robust NP effect to appear.

In addition, we also attempted to generalize any effects of perceptual load in the prime across several situations of perceptual load in the probe. This was important both for generalizing our perceptual load hypothesis and for considering the role played by prime–probe similarity in NP. Recent studies have shown that increased similarity between prime and probe displays can result in an increased magnitude of NP (Fox & De Fockert, 1998; Neill, 1997), and we assumed that prime and probe displays were more similar to one another when they both involve similar relevant set sizes. Thus, within the following experiments we manipulated perceptual load for the target processing in the prime, and across experiments we also varied load in the probe displays.

Experiment 1

Figure 1 shows examples of the stimuli used in the different conditions of Experiment 1. As can be seen from the figure, participants were presented with pairs of successive prime–probe displays and were requested to make speeded choice responses between the target letters *s*, *x*, or *n* in every display. The target letter of the prime displays appeared in one of six positions, arranged in a row at the display center, and participants were instructed to ignore an irrelevant distractor presented in the periphery above or below the display center. Probe displays always included a neutral distractor, but the probe target involved either repetition of the prime distractor (in Condition IR), or the prime target (in Condition AR), or no repetition (in Condition C), thus allowing us to assess priming effects from the prime target (AR) and the prime distractor (IR).

Perceptual load was manipulated only for the prime display, with the prime target appearing either with five additional neutral nontarget letters in a row (relevant set size 6) or with no nontarget items (relevant set size 1). Any NP from the peripheral prime distractor was assessed as a function of the perceptual load in the target processing of the prime. The probe displays always involved just one target and one peripheral distractor letter (i.e., relevant set size 1), and the target was presented in one of two central display positions (see Figure 1).

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[1] Response association strength for each one of the distractors may be weakened with more distractors because of nonattentional factors such as reduced processes of learning and of establishing response associations across trials, or some conflicts occurring between the distractor responses themselves that may lead to the distractors inhibiting one another (e.g., via processes of lateral interactions; Houghton et al., 1996) within any trial. Such cases are less informative for the main issue of our study, which concerns the extent to which attention can affect distractor processing.

[2] With greater load, more attention may be drawn to the target processing, and this may enhance any effects of priming for the targets. On the other hand, repetition priming as measured in the present task may be largely determined by nonattentional factors (e.g., motor facilitation in repeating the same key presses), thus limiting any influence from attentional factors such as load.

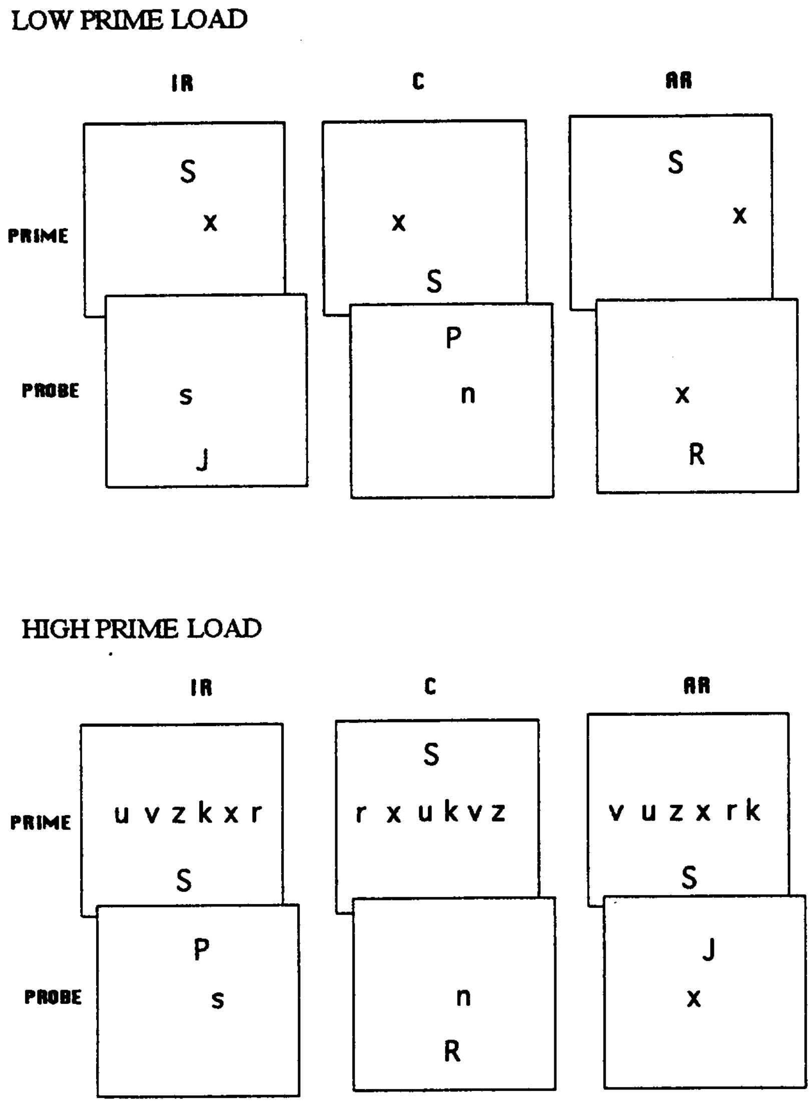

Figure 1. Example displays from the low prime load and high prime load conditions in Experiment 1. IR = ignored repetition; C = control; AR = attended repetition.

We predicted that the perceptual load involved in processing the prime target will determine NP from the prime distractor such that any NP effects will be observed under low perceptual load (relevant set size 1) and will be reduced or eliminated with higher perceptual load (relevant set size 6). We made no predictions about the impact of perceptual load on positive repetition priming from prime targets, because our hypothesis is concerned only with the processing of irrelevant distractor items. As discussed previously, we included AR trials only to maximize the NP from irrelevant distractors (see Fox, 2000; Kane et al., 1997).

Method

Participants. Sixteen undergraduate students from the University of Essex participated in the experiment in return for £3.00 for a 40-min session. All participants had normal or corrected-to-normal vision. The data for one of the participants were not collected because of a computer failure; thus the analyses of results were based on the remaining 15 participants.

Apparatus and stimuli. Stimulus presentation and data collection were controlled by an IBM-compatible PC attached to a VGA color monitor. The software used for creating and running the experiment was Micro Experimental Laboratory (MEL Version 1: Schneider, 1988). The participants viewed the computer screen through a custom built "viewer" that kept the eyes approximately 56 cm from the screen.

All of the letters were presented in a light gray color (No. 7 in the MEL color palette) on a black background. Target letters were lower case letters (*s*, *x*, or *n*—each requiring a different keyed response), and at a viewing distance of 56 cm, they each subtended a visual angle of about 0.61° vertically and 0.51° horizontally and were separated by approximately 1.02° nearest edge to edge from any adjacent letters in the same row. Distractor letters (in upper case), subtending a visual angle of 1.02° vertically and 0.51° horizontally, appeared randomly and equiprobably either above or below the center. The distance between the distractor edge and the fixation point was 1.73°. On the prime displays in the low load condition, the target letter appeared alone at one of six equally probable positions arranged in a row at the center of the screen. In the high-load condition, the prime target letter was accompanied by five nontarget letters (*v*, *u*, *z*, *k*, and *r*) that had no association with any response in the experiment. These five nontargets occupied the other positions in the central row equally often, in a random order. On the probe displays, a target letter appeared in one of two central locations on the immediate left or right of fixation, with a distractor letter appearing randomly and equally probably either above or below the center. On probe displays, the distractor letter was always neutral in relation to the targets (the capital letters, *P*, *R*, or *J*, which had no associated response in the experiment). Targets and distractors never appeared in the same position between the prime and probe.

Design and procedure. Each trial consisted of a prime display and a probe display. In the prime displays, all of the distractor letters were incompatible with the response required to the current target and were equally likely to be *s*, *x*, or *n*. Any priming effect from the irrelevant prime distractor was assessed on the subsequent probe display. There were three priming conditions. In the AR condition, the probe displays contained a target that was identical to the target in the prime display. The distractor letters always differed between prime and probe displays (e.g., a Target *s* with a Distractor *X* followed by a Target *s* with a Distractor *P*). In the C condition, the probe displays contained target and distractor letters that were different from the prime display (e.g., a Target *s* with a Distractor *X* followed by a Target *n* with a Distractor *P*). In the IR probe condition, the target in the probe display had the same identity as the distractor in the previous prime display (e.g., a Target *s* with a Distractor *X* followed by a Target *x* with a Distractor *J*).

The low- and high-load conditions were presented in separate blocks of trials. Five blocks of 54 trials (54 prime displays and 54 probe displays) were run for each load condition. One half of the sample received first the low load blocks and then the high load blocks; the other half got the reverse order. The first block of each of the load conditions was considered practice, and its results were excluded from the analysis. Thus, there were 432 experimental trials in total (216 low load and 216 high load), and there were 72 AR, 72 C, and 72 IR trials in each of the low- and high-load conditions. Participants could take a short break halfway through the experiment if they wished. The participants initiated each block by pressing the space bar. The order of trials within blocks was completely randomized.

Before each trial, a light-gray fixation dot was presented at the center of the screen for 1,000 ms. This was immediately replaced by the prime display, which appeared for 100 ms. Participants used the numerical keys on the right-hand side of the computer keyboard to make their responses. They were required to press the Number 1 key with their index finger for the target letter *s*, the Number 2 key for the target letter *x* with their second finger, and the Number 3 key for the target letter *n* with their third finger. Participants were encouraged to respond as fast as they could while avoiding errors. Feedback on errors was given by means of a 500 ms computer tone. Following the response to the prime display, there was a blank screen presented for 350 ms, and then the probe display was presented for 100 ms. Participants used the same response mappings for the probe display as they did for the prime display. Following their response to the probe display, there was an intertrial interval of 1,000 ms before the next trial began.

Results and Discussion

The mean reaction times (RTs) and percentage error rates were calculated as a function of the experimental conditions. Trials with RTs of less than 100 ms or more than 1.5 s were excluded from the RT analysis. This resulted in excluding 1% of the responses to the probes and 4% of responses to the prime.

Table 1

Experiment 1: Mean Response Times (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Load and Conditions of Priming

Prime load	Priming condition IR	C	C − IR	AR	C − AR
Low					
M	634	612	−22*	540	72*
SE	38	34		23	
% error	4	2	−2*	3	−1
High					
M	642	656	14	525	131*
SE	28	30		18	
% error	5	6	1	2	4*

Note. IR = ignored repetition; C = control; AR = attended repetition. *$p < .05$.

Prime display. One-way within-subject analyses of variance (ANOVAs) were conducted on the mean correct RTs and on the mean error rates, with the variable of load (high vs. low). These analyses revealed a main effect for load on both prime RTs, $F(1, 14) = 30.3, p < .001$, and prime error rates, $F(1, 14) = 10.7, p < .01$. Low load had a mean RT of 619 ms and a mean error rate of 5%. These were increased to a mean RT of 766 ms and a mean rate of 13% errors in the high-load condition. Thus, these analyses show that load was effectively manipulated in the target processing of the prime display, with poorer performance under high load, as expected.

Probe display. Table 1 presents the mean probe RTs and error rates as a function of prime-load and priming condition. Trials with errors and trials preceded by an error (on the prime display) were excluded from the probe RT analysis. A two way within-subject ANOVA was run on the critical distractor condition (IR, C) crossed with load (low, high). There were no main effects for load or distractor condition ($p > .20$, for either effect); however, there was a significant interaction between distractor condition and prime load $F(1, 14) = 10.2, p < .01$. As predicted from our hypothesis, significant NP from IR distractors was obtained under low prime load, $F(1, 14) = 6.2, p < .03$, but not under high prime load, in which there was in fact a nonsignificant trend for positive priming from the IR distractor, $F(1, 14) = 3.62, p < .08$ (see Table 1). A similar ANOVA on the error rates replicated the NP effect under low load, $F(1, 14) = 5.8, p < .03$, and showed a similar interaction between load and distractor condition, although this reached only marginal significance on the error rates, $F(1, 14) = 4.0, p < .07$. No effect was found for distractor condition under high load in the errors ($F < 1$).

Thus, the present results demonstrate that perceptual load in the processing of the prime target can determine negative priming effects from an irrelevant distractor. On inhibition accounts (e.g., Tipper, 1985), the NP effects from the distractor under low load reflect the active inhibition of irrelevant distractor representations. With higher load, no NP effects were found; in fact, there was a nonsignificant trend for positive priming on RTs. Because this trend was not significant in this experiment nor in any of our subsequent experiments, we shall not discuss it any further, except to note that NP was clearly absent with high load. Thus, we conclude that there was no evidence for distractor inhibition in the high-load condition; NP depended on the load in the processing of the prime target and was obtained only in conditions of low perceptual load.

In an ANOVA on the priming conditions AR and control crossed by load, there was no main effect for load, ($F < 1$), but there was a main effect of priming, $F(1, 14) = 37.6, p < .001$, and a significant interaction between load and priming, $F(1, 14) = 23.8, p < .001$. As can be seen in Table 1, the positive priming effect found from AR targets at the low load (72 ms) was substantially increased in the condition of high load (131 ms). This interaction was also replicated in the error rate analysis, $F(1, 14) = 5.2, p < .04$ (see Table 1). This result of increased positive priming from AR targets with higher load in their processing may indicate that the targets engaged more attention in the high-load situation (but see Note 2). The finding of increased priming in these conditions is in accordance with previous reports of attentional effects on priming (e.g., Johnston & Dark, 1986; Lavie, 1997).

The most important finding from Experiment 1, however, was the effect of attentional load on NP from an irrelevant distractor. Experiment 1 demonstrated that a reliable NP effect was obtained only under a situation of low perceptual load in the processing of prime targets. In the next experiment, we sought to replicate this result in a situation that allowed us to rule out some alternative explanations for it.

Experiment 2

The aim of Experiment 2 was to replicate the effect of perceptual load in prime processing on NP, in a situation of high perceptual load in the probe displays. This seemed important for confirming that NP depends specifically on the perceptual load in the processing of the prime rather than on some more general task load whereby making any aspect of the task harder, be it prime or probe, might remove NP.

In addition, Experiment 2 examined an alternative account for the effect of prime load in Experiment 1. Because all of the probe displays in Experiment 1 involved low perceptual load, the relative similarity between prime and probe displays varied between the conditions of prime load. In the low-load condition, both the prime and probe displays had a relevant set size of one item and were therefore more similar to one another than in the high-load condition (in which the prime displays had a relevant set size of 6, whereas the probe displays had a relevant set size of 1, see Figure 1). Thus, it could be argued that the similarity between the prime and probe displays was the major factor determining the results of NP in Experiment 1, with greater NP obtained in the low- versus high-load conditions because of the greater similarity between primes and probes in the low versus high loads. Greater similarity between displays can presumably facilitate processes of retrieval, and this in turn may enhance any NP effect due to a memory component in the effect (see Fox & de Fockert, 1998; Neill, 1997).

Experiment 2 allowed us to test this alternative account. In Experiment 2 all of the probe displays had high load, and this resulted in the relative similarity between the prime and probe displays being reversed between conditions of load by comparison with Experiment 1 (see Figure 2). Thus, the prime and probe displays were now more similar to one another in the high prime-load condition (in which both displays involved a relevant set size of 6) as compared with the low prime-load situation (in which the prime displays had a relevant set size of 1, whereas the probe displays had a relevant set size of 6). If similarity between the prime and probe displays is crucial for NP, then more NP should be found in the condition of high prime-load (which now had more similar displays between the primes and probes). However, if low perceptual load in the prime processing is crucial for NP, as we hypothesize, then we should again find more NP under the condition of low perceptual load (with dissimilar prime and probes), in accordance with our previous results.

Method

Participants. Twenty-six undergraduate students from the University of Essex participated in the experiment in return for £4.00 for a 50-min session. All participants had normal or corrected-to-normal vision. None had taken part in Experiment 1.

Apparatus and stimuli. The stimuli and apparatus used were identical to those in Experiment 1. As before, perceptual load was manipulated only in the prime displays, and the high- and low-load displays were identical to those of the previous experiment. The only difference from Experiment 1 was that all of the probe displays in the present experiment now had high load, rather than all having low load. Targets and distractors were never presented in the same positions on both prime and probe displays, and the probe targets were equally likely in any of the other positions in the row following any target position in the prime.

Design and procedure. The design and procedure were identical to those of Experiment 1 except for the fact that all of the probe displays now involved search for the target among five other neutral nontarget letters in a central row of letters (see Figure 2). Thus, as before, perceptual load was manipulated only on the prime display, but this time the probe displays always involved high load.

Results and Discussion

Mean RTs and error rates were calculated for each participant. Due to the longer overall RTs in this experiment (see Table 2), a 2-s cutoff point was used for the calculation of mean RTs. This resulted in only 1% of responses to the prime and probe displays being excluded (whereas using our previous RT cutoff point of 1.5 s would have excluded 6% from the total of responses).

Prime display. Trials with errors were excluded from the RT analysis. There was no significant difference between prime RTs in the low load (mean RT of 770 ms) and the high load (mean RT of 780 ms) conditions ($F < 1$, in a one way ANOVA with the variable of load). However, a significant effect of load was found on the error rates, $F(1, 25) = 17.9, p < .001$. The mean error rate of 6% in the low load condition was increased to a mean rate of 12% in the high load. Thus, although our manipulation of load did not involve a significant increase in the prime RTs, the increase in error rates with higher load allows us to confirm that the prime task did indeed become more difficult in the high-load condition where

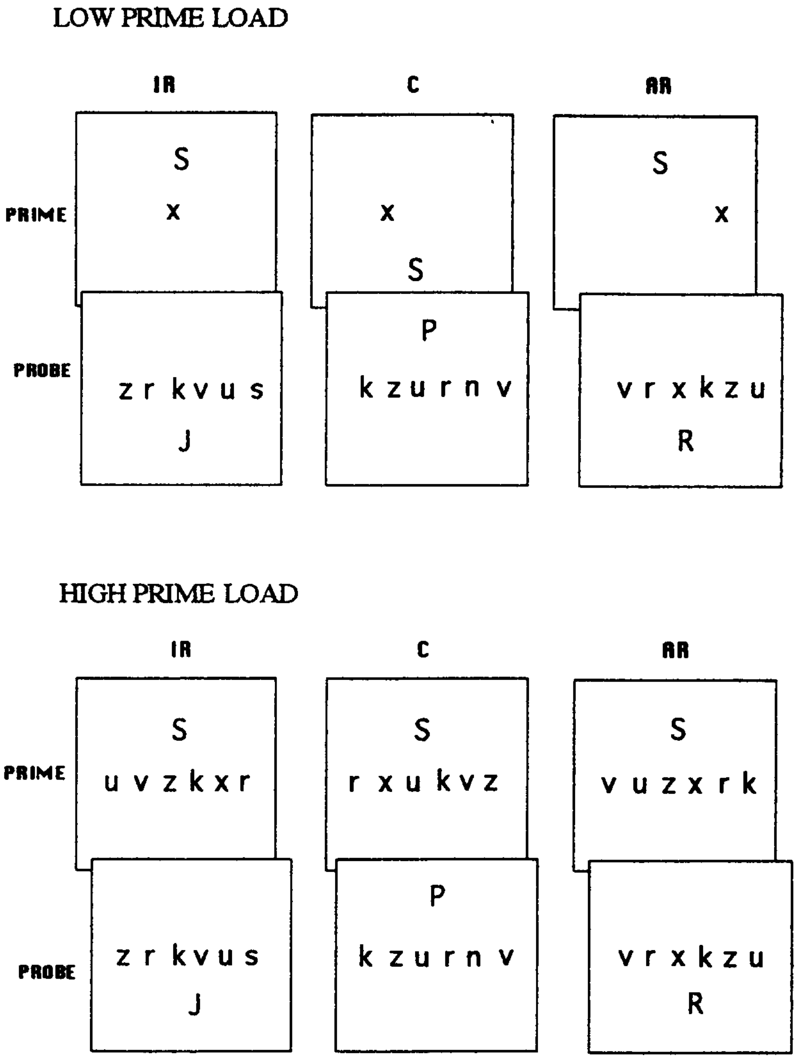

Figure 2. Example displays from the low prime load and high prime load conditions in Experiment 2. IR = ignored repetition; C = control; AR = attended repetition.

the target had to be searched for in a row of neutral nontarget items.[3]

Probe display. Table 2 presents the mean RTs and error rates as a function of load and priming condition. Trials with errors and trials preceded by an error were excluded from the RT analysis. In a two-way ANOVA with the factors of distractor condition (IR, C) and prime-load, there was no main effect for either load or distractor condition ($p > .10$ for both main effects), but there was a significant interaction between the two factors, $F(1, 25) = 7.8, p < .01$. A reliable NP effect was found in the low-load condition, $F(1, 25) = 8.35, p < .01$, but not in the high-load condition ($F < 1$; see Table 2). Error rates did not vary significantly between the distractor conditions ($p > .10$ in all comparisons; see Table 2); thus we base our conclusions on the RT analyses. In conclusion, Experiment 2 confirmed our hypothesis that NP crucially depends on the perceptual load in the processing of the prime displays rather than on general task load (i.e., regardless of whether this is high in the prime or probe display), or on similarity between prime and probe displays.

To reveal any effects from target repetition, we also ran an ANOVA comparison of the RTs between the priming conditions AR and C as a function of prime load. This analysis revealed just a significant main effect of priming, $F(1, 25) = 33.2, p < .001$ ($F < 1$ for any of the other effects). As can be seen in Table 2, target repetition facilitated RTs to the same extent (105–106 ms) in both load conditions. A similar result was found in the ANOVA

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[3] The absence of any increase in overall prime RTs with higher load in Experiment 2 seems to be attributed to the increase in prime RTs in the low-load condition of this experiment (compare 619 ms with 760 ms in the low-load conditions of Experiments 1 and 2, respectively). Perhaps the situation of high load in the probes of Experiment 2 overshadowed the main effect of load in the prime. Thus, it could be that the high proportion of high-load displays (75%) in this experiment led the participants to slow down their responses on all of the trials (i.e., on prime trials as well as probe trials). The relationship between relevant set size and the proposed increase in attentional load is established more precisely in the next experiment.

Table 2
Experiment 2: Mean Response Times (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Load and Distractor Condition

Prime load	Priming condition				
	IR	C	C − IR	AR	C − AR
Low					
M	913	878	−35*	774	104*
SE	34	35		35	
% error	18	17	−1	13	4
High					
M	852	853	1	751	105*
SE	26	32		27	
% error	14	15	1	12	3

Note. IR = ignored repetition; C = control; AR = attended repetition.
$^{*}p < .05$.

comparison of the error rates between AR and C, which also showed just a main effect of positive priming, $F(1, 25) = 5.1, p < .003$ ($p > .10$ for the interaction). Thus, Experiment 2 did not replicate the increase in positive repetition priming from repeated targets in high- versus low-load conditions that was found in Experiment 1, although this is irrelevant to our predictions. We defer our conclusions about the role of load in repetition priming from attended targets until the discussion of the results from Experiment 3, which also examined repetition priming under different levels of load.

As in Experiment 1, NP depended on the perceptual load in the processing of prime targets and was obtained only in conditions of low perceptual load in the prime display. Moreover, our finding that the effect of prime perceptual load can generalize across conditions of load in the probe (i.e., high load in Experiment 2, low load in Experiment 1) allows us to reject alternative accounts for the effect of prime load on NP in terms of the relative similarity between the prime and probe displays, because this was reversed between the conditions of prime load across the two experiments.

Experiment 3

Experiment 3 further explored the relationship between perceptual load for the relevant prime target and NP from ignored distractors, by examining NP as a function of a *graded* increase in the target processing load. Thus, in Experiment 3 we compared priming from distractors in prime displays that had relevant set sizes of one, two, four, and six items in the central search area. In addition, we sought to confirm that our previous manipulations of relevant set size had indeed varied the demand on attentional capacity. By gradually varying the number of items among which the target appeared in the prime, we could now examine the target search function. If every additional nontarget item increases the demand on attentional capacity, then one might expect a linear increase in prime RTs as a function of set size. The question of main interest here was whether NP from an irrelevant distractor would also vary as a function of the graded increase in search load for the target.

To keep target eccentricity equivalent between all set sizes, the target and nontarget letters for the relevant search task were now presented in a circular array situated at the center of the display. As before, one irrelevant distractor letter also appeared in each prime and probe display, in a peripheral position outside the central circle of relevant letters. Priming effects from this irrelevant distractor were assessed as a function of the relevant search set size. One important difference between Experiment 3 and the previous experiments was that relevant set size in the prime displays now varied in a random manner between trials, in an intermingled sequence. This was done to eliminate any potential strategy-based differences between the different load conditions that might apply when the load could be anticipated.

Method

Participants. Twenty undergraduate students from the University of Essex participated in the experiment in return for £4.00 for a 50-min session. None had taken part in Experiments 1 or 2. All participants had normal or corrected-to-normal vision. One individual reported paying attention to the prime distractor (in an attempt to predict the target of the next trial, from the distractor), and we excluded his results from any of the analyses.

Apparatus and stimuli. The apparatus used was identical to that of the previous experiments, and the same letters were used for the targets and distractors. However, unlike in the previous experiments, the target letter of the prime now appeared at one of six equally probable positions arranged in a circular array. There were four load conditions for the prime displays. In the Set 1 condition, the target letter was presented alone in one of the six relevant locations. In the Set 2 condition, a single nontarget letter (either *v*, *u*, *r*, *k*, or *z*) was presented in an adjacent position to the target. In the Set 4 condition, three different nontarget letters from this set were presented along with the target, and in the Set 6 condition, the prime target letter was accompanied by all five nontarget letters (*v*, *u*, *z*, *k*, and *r*). The five nontarget letters occupied each position in the circle equally often, in a random order. In the Set 2 condition, the nontarget letter was equally likely to appear on the left or the right of the target, and in Set 4, the location of the whole group was counterbalanced, as was the likelihood of the target appearing on the edge of a group or in an internal position within a group. In the Set 6 condition, the letters formed a complete circle. The circle's radius, measured to the center of the letters, was 2.3° of visual angle. The edge-to-edge separation between adjacent letters around the circular array was approximately 1.5° of visual angle. The distractor appeared randomly and equally probably 2.25° of visual angle to the far left or right of the centrally located circular display. The separation from the fixation point to the nearest edge of the distractor letter was 4.4° of visual angle. For the probe displays, the target letter always appeared in two positions on the left or right side of the imaginary radius of the central circle, with no other letter in the circle positions. As in the prime displays, the probe target was always accompanied by one distractor letter that appeared randomly and equally probably either to the left or to the right of the central display, and it was always neutral in relation to the targets (the capital letters *P*, *R*, or *J*, which had no defined response in the experiment). As before, targets and distractors were never presented in the same position between the prime and probe displays.

Design and procedure. The design and procedure were identical to those in the previous experiments except for the following changes. The four load conditions (Set 1, Set 2, Set 4, and Set 6) were randomly intermixed within each block of trials. Each participant underwent a practice block of 54 trials followed by 6 blocks of 72 trials (72 prime displays and 72 probe displays). The results from the practice block were excluded from the analysis. Thus, there were 432 experimental trials in total (108 trials in each of the load conditions). For each load condition, all

108 prime distractors were response incompatible. For the probe displays, there were 36 AR, 36 C, and 36 IR trials in each of the four load conditions (Set 1, Set 2, Set 4, and Set 6). Participants could take a short break halfway through the experiment if they wished. The participants initiated each block by pressing the space bar. The order of trials and load conditions within blocks was randomized.

Results and Discussion

The mean RTs and percentage error rates were computed as a function of the experimental conditions and are presented in Table 3 and Figure 3. Trials with RTs of less than 100 ms or more than 1.5 s were excluded from the RT analysis. This resulted in excluding 1% of the probe responses and 6.4% of the prime responses.

Prime display. Figure 3 shows the prime RTs plotted as a function of set size. As can be seen in the figure, RTs showed a linear increase with set size, with a slope of 33 ms per item, and this was confirmed in a one-way ANOVA on the correct prime RTs with the variable of set size, $F(3, 16) = 44.7, p < .001$, and in a trend analysis that showed a highly significant linear component, $F(1, 18) = 112.97$, $p < .001$. There was also an increase in error rates with set size, $F(3, 16) = 5.3, p < .01$, as can be seen in Figure 3.

These results confirm that our manipulation of relevant set size did indeed increase the load in the relevant processing, with each additional item apparently imposing an increased demand on focused attention. The present results also demonstrate that the effect of set size is not based on differences in processing strategies among the load conditions, because set size was now varied randomly and unpredictably between trials, thus discouraging strategy shifts between trials.

Probe display. Trials with errors and trials preceded by an error were excluded from the RT analysis. A two-way within-subject ANOVA was run on the probe RTs as a function of distractor condition (IR, C) and prime set size (1, 2, 4, 6). There was a main effect for distractor condition, $F(1, 18) = 8.9, p < .01$, but not for set size, $F(3, 16) = 1.5$, *ns*. Thus, the linear increase in prime RTs with set size in the prime display did not lead to any slowing of RTs to the probe displays with their constant set size. More important, there was a significant interaction between distractor condition and set size, $F(3, 16) = 3.27, p < .05$. This interaction seems to reflect a general decrease in NP with set size (see Table 3).

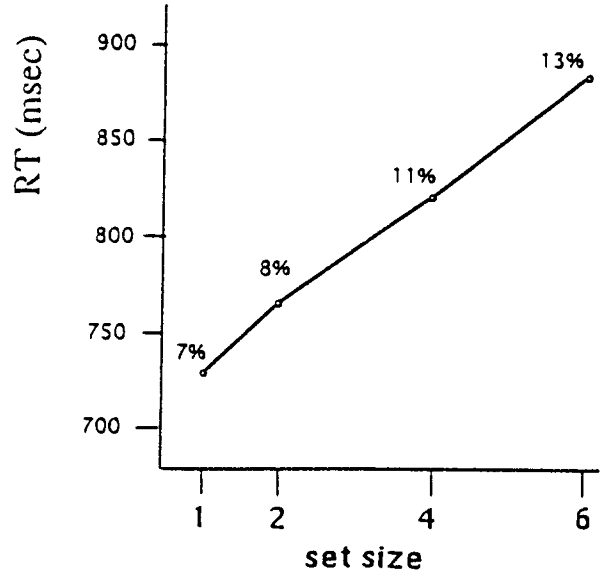

Figure 3. Experiment 3: Mean response time (RT) and percentage error for performance in the prime displays, plotted as a function of the relevant search set size.

Table 3

Experiment 3: Mean Response Times (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Relevant Search-Set Size and Distractor Condition

	Priming condition				
Set size	IR	C	C − IR	AR	C − AR
One					
M	669	612	−57*	534	78*
SE	31	32		23	
% error	4	6	2	3	3*
Two					
M	645	621	−23	544	77*
SE	31	32		22	
% error	4	5	1	3	2
Four					
M	647	616	−29	539	77*
SE	30	30		20	
% error	3	5	2	5	0
Six					
M	615	615	0	534	81*
SE	34	34		22	
% error	4	4	0	4	0

Note. IR = ignored repetition; C = control; AR = attended repetition.
*$p < .05$.

To further examine how NP varied with set size, we compared the magnitude of NP between the set sizes by using *F* contrasts. We first sought to confirm that the results from set size 1 and set size 6 replicated our previous findings. Indeed, as in our previous experiments, there was a significant difference between the fairly large NP effect obtained at set size 1 and the 0-ms NP at set size 6 in the present experiment, $F(1, 18) = 8.0, p < .01$. Priming did not differ between set sizes 2 and 4 ($F < 1$), and their average NP effect was significantly reduced by comparison with the NP effect for set size 1, $F(1, 18) = 6.8, p < .018$, (see Table 3). Further *F* comparisons of IR and C in each one of the set sizes using the Bonferroni adjusted *p* value of .0125 (i.e., .05/4) confirmed that the NP effect at set size one was significant, $F(1, 18) = 13.3$. However, although there was a trend toward NP in both set sizes 2 and 4 (see Table 3), neither of these trends reached significance, $F(1, 18) = 2.1$, for set size 2 and $F(1, 18) = 4.2$, for set size 4.[4] Error rates did not produce any significant effects ($p > .10$, in all their ANOVA comparisons between IR and C), thus we base our conclusions on the RT analyses.

From these analyses we can conclude then that NP from irrelevant distractors depends on the relevant processing load, with

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[4] The average NP effect across set sizes 2 and 4 did reach .05 significance when not corrected for the multiple comparisons.

gradual increases in the load of relevant processing leading to a gradual decrease in the NP effects from the irrelevant distractor. This effect of load in relevant processing on the irrelevant processing of the distractors seems unlikely to be based on any difference in strategies between conditions of load, because in Experiment 3 the levels of load changed randomly and unpredictably in an intermingled sequence of trials, thus discouraging any strategy shifts between conditions.

We note that the NP effect of 57 ms that was obtained in the set size 1 condition of Experiment 3 was larger than any of the NP effects we found in the condition of set size 1 for our previous experiments (these ranged between 22 and 35 ms in the previous experiments). Because the level of relevant load at set size 1 seemed equivalent between Experiment 3 and the previous experiments, perhaps some other characteristics of Experiment 3 contributed to the larger NP found in its low-load condition. For example, different arrangement of items between experiments (e.g., a circular array with a right or left distractor, in Experiment 3, versus a horizontal row with a distractor above or below, in Experiments 1–2). Or perhaps the involvement of some intertrial switching between conditions of load in Experiment 3 could have contributed to the larger NP in its set size 1 condition.

The important point, however, is that although NP is known to be affected by various factors other than relevant processing load (e.g., Fox, 1994; Moore, 1994), which may have contributed to some variation in the size of NP effect between our experiments, our important conclusions about the role of load in NP were all based on comparisons of NP between different relevant set sizes *within* each experiment, and the critical interaction between load and NP was consistently obtained in all of our experiments, regardless of any variations in the size of NP effect between them.

Finally, Experiment 3 did not find any significant effect of load on positive priming from the attended targets. In the RT comparisons of AR and C, there was a main effect of positive priming, $F(1, 18) = 21.7, p < .001$, which did not vary with load ($F < 1$). The error rate comparisons of AR and C revealed only a significant effect of positive priming at set size 1, and there were no other significant effects in the error analyses ($p > .05$ for all other effects). Thus, load did not seem to play an important role in the positive priming effects from the targets in this experiment. Overall then, a robust facilitatory effect of repetition priming was obtained from attended targets in all of our experiments. This effect of repetition priming did not typically interact with perceptual load, except in Experiment 1. Perhaps repetition priming effects were not increased by higher loads in the rest of our experiments because repetition priming was already near ceiling in the situations of low perceptual load in Experiments 2 and 3. (See the fairly large effects of priming from attended targets under low loads in Tables 2–3.)

Experiment 4

The previous three experiments demonstrated that high perceptual load in the relevant processing of a prime display (6 items) eliminates negative priming from an irrelevant distractor. In contrast, when perceptual load is low (1 item) an irrelevant distractor produces strong negative priming. Our interpretation of these results follows directly from the perceptual load hypothesis (e.g., Lavie, 1995): Processing of the target in the high-load condition consumes attentional resources so that there are no resources left for processing of the distractor, and hence no need to inhibit it. However, when the perceptual load of the relevant display is low, perceptual resources flow over and processing of the irrelevant distractor occurs. Correct selection of responses in such cases therefore requires some means of suppressing distractor responses, which then results in NP effects in subsequent responses toward the distractor. Previous support for this notion comes from the finding that concurrent flanker interference effects are found typically in conditions of low perceptual load and eliminated by higher perceptual load (see Lavie, 1995, in press; Lavie & Cox, 1997; Lavie & Tsal, 1994).

Our assumption was that the prime display in the current experiments was similar to flanker tasks in previous studies (e.g., Lavie, 1995, Experiment 1) and that the absence of negative priming in the probe displays following high prime load indicates that the distractor was not processed during the prime displays. However, there is an alternative explanation of the results that may challenge this interpretation. Some investigators have argued that inhibitory processing requires attentional capacity so that, for example, three distractors cannot be inhibited as effectively as one (Engle et al., 1995; Neuman & DeSchepper, 1992; Neuman et al., 1993). This view would suggest that distractors may be activated on both conditions of low and high prime load but that the capacity demands of processing targets and nontargets in the high-load conditions reduce the ability to inhibit an additional distractor and therefore result in reduced negative priming from this distractor.[5] In this view then, load directly reduces distractor inhibition without affecting its activation; thus although NP effects are reduced with load, concurrent distractor interference effects should remain unaffected by load. We think that this is unlikely, given the previous demonstrations that distractor interference effects in concurrent responses typically are reduced or eliminated under high-load conditions with a task very similar to that used here (e.g., Lavie, 1995, Experiment 1; Lavie & Cox, 1997, Experiment 2).

Nevertheless, we thought it was prudent to examine in a single experiment whether high perceptual load in relevant processing reduces both distractor interference effects in concurrent responses and negative priming effects in subsequent responses. This is the prediction of the perceptual load hypothesis. The alternative hypothesis of distractor activation with reduced inhibitory capacity under high load, discussed above, would predict distractor interference but no negative priming under high-load conditions. The aim of Experiment 4 was to distinguish between these two hypotheses.

Thus, in Experiment 4 we manipulated load in the prime displays and assessed the effects of prime load on concurrent distractor interference (measured in the prime RTs), as well as subsequent NP effects (measured in the probe RTs). The prime displays involved either an incompatible distractor or a neutral distractor, to provide us with a measure of concurrent interference effects from the distractor in the prime. The probe displays involved IR and C conditions as before, to assess the subsequent effects of NP from the prime distractor. The high-load probe displays of Experiment 2 were used for the probes in this experiment, as this design can

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[5] We thank an anonymous reviewer for suggesting this alternative account.

Table 4

Experiment 4: Mean Response Times (ms), Standard Errors, and Percentage Errors for Performance in the Prime Displays as a Function of Prime Load and Distractor Conditions

	Response compatibility condition		
Prime load	I	N	N − I
Low			
M	784	728	−56*
SE	31	29	
% error	5	4	−1
High			
M	816	811	−5
SE	29	30	
% error	7	9	2

Note. I = incompatible; N = neutral.
* $p < .05$.

clearly dissociate the effects of load from the potential effects of prime–probe similarity. (See our discussion in the introduction to Experiment 2.) In addition, the design of Experiment 2 was the least similar to Lavie's previous flanker studies (which never involved high-load displays in conditions of low perceptual load). Replicating the effects of load on flanker interference as well as NP within this new design can thus add to the generality of the load hypothesis.

Method

Participants. Twelve undergraduate students from the University of Essex and 4 from University College London participated in the experiment in return for £4.00 for a 50-min session. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. Stimulus presentation and data collection were controlled by the same equipment and software as used in the previous experiments. The stimulus displays were identical to those of Experiment 2 (thus all the probe displays carried high load, whereas half of the prime displays had high load and the other half had low load), with one exception: A neutral distractor was presented on half of the prime displays (and an incompatible distractor presented on the other prime displays) so that a measure of flanker interference could be obtained. The letters *P*, *R*, or *J* were used for the neutral distractors on both the prime and probe trials.

Design and procedure. The general procedure, presentation times, and sequence of events on each trial were the same as in our previous experiments. Half of the prime displays with incompatible distractor were followed by probe displays with this distractor as the target (providing us with an IR condition); the other half of the incompatible prime displays were followed by probe displays that did not repeat any of the prime letters (providing us with a C condition). Half of the prime displays with a neutral distractor were followed by a probe display with the same target letter (AR condition); the other half was followed by a probe display that repeated no letters from the prime (providing us with a neutral control [NC] condition for the comparisons involving AR) and also ensuring that the participants could not anticipate target repetition following prime displays with a neutral distractor.

The low and high perceptual load conditions were presented in alternating blocks (low, high, low, high, etc). One half of the sample received a low-load block first, followed by high, low, high, etc; the other half got the reverse order (high, low, high, low, etc). Each participant started with 2 short practice blocks of 24 trials each (one for each load condition), which were followed by 8 blocks of 72 trials (72 prime displays and 72 probe displays).

Results and Discussion

The mean RTs and percentage error rates, calculated as a function of the experimental conditions, are presented in Tables 4 and 5. One of the participants had very high error rates (32% errors in the prime displays, 66% errors in the probe displays), and his results were therefore excluded from any further analyses. For the rest of the participants, the average error rates were 6% in the prime displays and 10% in the probe displays. As in Experiment 2 (which also had a high load in all its probe displays), overall RTs in this experiment were again fairly long and we therefore used a cutoff point of 2 sec. This cutoff resulted in excluding just 1% from the responses to the prime and the probe displays.

Prime display. A two-way within-subject ANOVA on the mean correct RTs with the factors of load (high, low) and distractor compatibility (incompatible, neutral) revealed main effects for load, $F(1, 14) = 23.1, p < .001$, and distractor compatibility, $F(1, 14) = 20.7, p < .001$. Of more importance was that there was a significant Load × Compatibility interaction, $F(1, 14) = 30.3, p < .001$. As predicted from our load hypothesis, the interference effect of 56 ms in the low load condition was significant, $F(1, 14) = 39.9, p < .001$, whereas the 5 ms interference effect in the high load condition was not significant, $F < 1$. None of the distractor compatibility effects reached .05 significance in the analyses of errors (see Table 4), thus we base our conclusions on the RT results. These RT results replicated Lavie's (1995, Experiment 1) findings of distractor compatibility effects at low loads (with relevant set size of one item), which were eliminated by a higher perceptual load (i.e., relevant set size of six items). This provided support for our claim that perceptual load in the relevant processing determines the extent of irrelevant distractor processing.

Probe display. The mean RTs and error rates as a function of the conditions of load and priming are presented in Table 4 (lower panel). Trials with errors and trials preceded by an error were excluded from the RT analysis. In a two-way within-subject

Table 5

Experiment 4: Mean Response Times (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Load and Distractor Conditions

	Priming condition					
Prime load	IR	C	C − IR	AR	NC	NC − AR
Low						
M	885	842	−43*	764	832	98*
SE	26	27		19	29	
% error	11	9	−2	11	7	−4*
High						
M	818	831	13	755	831	76*
SE	29	29		22	36	
% error	9	8	1	14	9	−5*

Note. IR = ignored repetition; C = control; AR = attended repetition; NC = neutral control.
* $p < .05$.

ANOVA on the factors of distractor condition (IR, C) and load, there was a significant interaction between load and distractor condition, $F(1, 14) = 9.4, p < .01$. As in our previous experiments, a significant NP effect was found in the low-load condition, $F(1, 14) = 10.8, p < .005$, but not in the high-load condition ($F < 1$; see Table 5). There were no significant effects ($p > .10$) in the ANOVA comparison of the error rates between the distractor conditions.

Thus, this experiment found again that high perceptual load in the target processing of the prime displays reduced NP from the prime distractors. More important the experiment provided evidence from the same task that perceptual load reduces effects of both concurrent interference and NP, thus it allows us to better relate the effect of load on NP to the extent of distractor processing in the prime. On this issue, the present results provided support for our hypothesis that perceptual load reduces NP by reducing the concurrent processing of distractors in the prime. The results also allow us to reject the alternative account, in which distractor inhibition was directly reduced by high perceptual load without affecting concurrent distractor activation.

An ANOVA comparison of the RTs between the conditions of AR and NC revealed again a facilitation of RTs to repeated targets, $F(1, 14) = 15.8, p < .001$, which did not vary with load ($F < 1$; see Table 5). The error rate analysis, however, revealed a significant increase in the number of errors in the condition of AR versus NC, $F(1, 14) = 10.7$, $p < .006$, which did not interact with load ($p > .10$). Thus, there was some trade-off between RTs and errors in the effects of target repetition. This pattern of results for AR targets was found for the first time in this experiment, and it is not clear what caused it. However, as we previously mentioned, AR effects from the targets are peripheral to our main concern with the processing of distractors, and we report them simply for the sake of completeness.

General Discussion

This study demonstrates that perceptual load in the relevant processing of prime displays plays an important role in NP from an irrelevant distractor. In four experiments, NP effects from ignored distractors were assessed during manipulations of load in the relevant processing of the prime target. In all of these experiments, we found that increases in the perceptual load of target processing in the prime display lead to a significant decrease in NP from irrelevant distractors as measured in a subsequent probe display.

Experiments 1, 2, and 4 allowed us to generalize the effects of perceptual load in the prime display on NP across different situations of load in the probe displays. Experiment 1 involved low perceptual load in all of the probe displays, and Experiments 2 and 4 involved high perceptual load in all of the probe displays. However, the three experiments showed a similar interaction between perceptual load in the prime display and the subsequent NP. Thus, we conclude that the effect of perceptual load on NP depends specifically on the processing load involved in the prime displays and not on any interaction between the load in the prime and the load in the probe or on some general level of task difficulty across the prime and probe.

These three experiments also ruled out alternative accounts for load in terms of relative similarity between the prime and probe displays in the different levels of load. Assuming that displays are more similar to one another when they involve the same rather than a different number of items (see Figures 1 and 2), the prime and probe displays were more similar to one another in the low-load relative to the high-load condition of Experiment 1. However, in Experiments 2 and 4 this similarity was reversed so that prime and probe displays were more similar to each other in the high-relative to the low-load condition. The fact that we found the same effect of perceptual load on NP across these variations in prime–probe similarity confirms that the effect of perceptual load on NP was not mediated by the relative similarity between prime and probe displays (and hence the potential ease of episodic retrieval of the preceding distractor, see Fox & De Fockert, 1998; Neill, 1997).

Experiment 3 verified that our manipulation of set size did indeed impose greater demand on attentional capacity. In Experiment 3 the relevant set size was varied in a graded manner (from 1 to 2, 4, or 6) and the search function with set size was highly linear, suggesting that the processing of each additional item required attention. More important, we found that NP also varied as a function of set size: As the relevant set size in the prime was gradually increased, NP effects gradually decreased. We note that although NP effects significantly decreased from set size 1 to set sizes 2 and 4, they were clearly eliminated only with set size 6. Thus, we conclude that stimuli, irrelevant as well as relevant, are processed as long as the relevant processing load does not involve more than approximately four items. This conclusion is in accordance with recent reports that capacity limits may be reached only at approximately four to five items (Fisher, 1982; Pylyshyn et al., 1994; Yantis & Jones, 1991). It also agrees with a recent demonstration (Lavie & Cox, 1997) that concurrent interference effects from distractors similarly depend on target-search load and are eliminated only with more than four search items.

Finally, Experiment 4 provided a further replication of the effect of perceptual load on NP and allowed us to better relate NP to concurrent processing of distractors. In this experiment, we included a measure of response competition effects from irrelevant distractors in the prime displays and found that distractor interference was substantially reduced by higher perceptual load (see also Lavie, 1995), as was NP. We conclude that high perceptual load in the relevant processing of the prime display results in reduced activation of the irrelevant prime distractors, so that no distractor interference or subsequent NP occurs.

Role of Perceptual Load in Distractor Inhibition

Although there is some dispute over the full explanation for all NP effects (see our discussion below), it seems that in most views, processes of distractor inhibition are assumed to be at least partially involved in generating NP. (See Neill & Valdes, 1996, for a comprehensive summary of the various accounts for NP.) Our finding that NP depends on the perceptual load involved in the processing of prime targets adds an important qualification to any inhibition-based account for NP. Our results imply that any processes of distractor inhibition must depend on the load involved in processing the relevant target, occurring only in situations of low perceptual load. Indeed, this is what we predicted from our perceptual load hypothesis, on which suppression of irrelevant distractors is required only under situations of low perceptual load, as only then are irrelevant as well as relevant stimuli processed. By contrast, situations of high perceptual load, which exhaust attentional capacity in the relevant processing, naturally result in selective perception on our account without requiring any active suppression of the distractors. Thus, in situations of high perceptual load, the distractors are not inhibited, they are simply not processed (e.g., Lavie, 1995; Neisser, 1976).

The present results support these predictions and corroborate previous claims (e.g., Lavie & Tsal, 1994) that higher target loads lead to reduced distractor processing. Lavie (1995; Lavie & Cox, 1997) found that concurrent interference effects from distractors depend on the perceptual load in target processing and occur only in conditions of low perceptual load. However, Lavie's previous results were open to an alternative account on which the reduced distractor interference with higher perceptual load might have been attributed to *increased* distractor inhibition rather than reduced distractor processing in situations of high versus low load. On this alternative account, a greater NP effect is predicted in conditions of high versus low load to reflect the greater distractor inhibition there. The present studies found the opposite pattern of results: More NP in conditions of low versus high load, allowing us to reject this alternative account.

Thus, our results support the view that selective attention does not always require active mechanisms for ignoring (e.g., inhibition). Active inhibition may be very important for avoiding potential conflicts between incompatible response tendencies that would otherwise arise in situations of low perceptual load. However, any need for such inhibition is much reduced in conditions of high perceptual load. These result in selective perception as a natural consequence of capacity limits in perception.

Active Versus Passive Mechanisms of Selection

We thus propose that selective attention involves (at least) two modes of selection: a *passive* selection mode, in which selective processing occurs as a natural consequence of exhausting available capacity in situations of high perceptual load, and an *active* selection mode, which allows for selective behavior by actively inhibiting competing response tendencies from the irrelevant stimuli when these are fully processed (i.e., only in situations of low perceptual load). This model also offers a compromise between early and late selection views of attention: Processes of early *perceptual* selection occur in situations of high perceptual load, and processes of late *response* selection also occur but only in situations of low perceptual load. (See Lavie & Tsal, 1994, for an extensive review of previous evidence consistent with these claims; see also Lavie, 2000, for a more detailed discussion of active versus passive modes of attentional selection.)

Our view can also be accommodated with recent reactive inhibition views, in which the degree to which distractors are inhibited is proportional to the extent to which they were activated, such that greater distractor activation requires greater suppression of the distractor (see Fox, 1994, 1998; Houghton et al., 1996; Malley & Strayer, 1995). We suggest that the perceptual load in target processing determines the degree of activation for the distractors, and consequently the degree to which any inhibition is required to suppress the irrelevant distractor activation. Thus, in both the present account and on recent reactive inhibition models, more inhibition is required for distractors in situations of low versus high perceptual load, because of the greater distractor activation in the low-load cases.

An important aspect of the present study is that our findings of reduced NP from distractors with greater target load cannot be attributed to any direct effect of reducing the strength of each distractor's association with responses, which may have been involved in previous manipulations of the number of distractors (cf. Houghton et al., 1996; Neumann et al., 1993). This is because our manipulation of load involved items that were not associated with any response in our task (i.e., added neutral nontarget letters), which only served to increase the load for the target search. Thus, in our study we can more safely relate the reduced NP to reduced perceptual processing of distractors rather than any weakening of their associations with responses (see also Footnote 1). Moreover, Experiment 4 allowed us to reject alternative accounts in which load may directly reduce capacity to inhibit distractors without affecting their activation, because we found that perceptual load reduced interference from distractors in concurrent responses as well as NP in subsequent responses. Thus, Experiment 4 confirmed our claim that high perceptual load reduces distractor processing and therefore leaves less of a distractor to inhibit.

Perceptual Load and Episodic Retrieval Accounts for NP

As we previously mentioned, alternative accounts of NP exist, and other processes have been postulated to produce NP in addition to, or instead of, processes of distractor inhibition. In particular, the effects of NP seem also to depend on the extent to which the distractor identity and its role (as irrelevant in the prime trial) are retrieved during the probe processing, at least in some situations. (See Fox, 1995; May, Kane, & Hasher, 1995; Neill & Valdes, 1996; Tipper & Milliken, 1996, for recent discussions of this issue.)

Our manipulations of perceptual load in the processing of the prime were not intended to directly affect any processes of distractor retrieval during the processing of the probe trials. Indeed, our findings that perceptual load effects on NP can generalize to different situations of contextual similarity between the prime and probe (e.g., as between Experiments 1 vs. 2 and 4) seem to make it unlikely that our effects were mediated by varying processes of retrieval, because these are largely dependent on contextual similarity (e.g., Anderson, 1983).

Nevertheless, we cannot completely rule out any involvement of possible episodic memory components to the present perceptual load effects on NP. For example, it is possible to argue that perceptual load in the relevant processing may affect encoding into memory of the irrelevant distractor. Perhaps reduced perceptual processing of the distractors would result in reduced encoding into memory for them and hence less NP in an episodic retrieval view (see Neill et al., 1992). Thus, the reduced NP we found with greater load may be attributed to reduced memory for the distractors in addition to or instead of their reduced inhibition.

Our experiments were not designed to distinguish between episodic retrieval and inhibition-based accounts for NP. Instead, we sought to establish a general role for relevant processing load in the processing of irrelevant distractors, as indexed by NP. Our conclusion that perceptual load in target processing can allow for a more passive mode of selective ignoring whereby the reduced perceptual processing for the distractors leads to a reduced need for any process of active rejection of those distractors still follows regardless of whether one adopts an inhibitory or episodic retrieval account for NP.

Note that in existing episodic retrieval accounts, irrelevant distractors are selected against by a process of "action tagging," which allows these distractors to be actively rejected as irrelevant for responses. It is this tag that is then held to produce NP, when the same identity subsequently requires response as the relevant probe target. Our results imply that under high load the response associated with the distractor was not even activated and hence did not require any process of tagging in order to maintain the correct selection of target responses for the prime.

Thus, although we cannot determine whether the NP effect in our situation of low perceptual load was due to active distractor rejection via process of response inhibition or via some process of action tagging, as postulated on episodic retrieval accounts, we can nevertheless conclude that with greater target processing load, there is no evidence that either of these active selection mechanisms is engaged. Future research investigating the precise effects of perceptual load in distractor processes of perception and inhibition or of entry into episodic memory should prove very useful for our understanding of selective attention. For example, testing the effects of memory load versus perceptual load on irrelevant distractor processing should provide a useful means of dissociating load effects on memory versus perceptual processes (e.g., Lavie & Hirst, 1999; Lavie, 2000). In addition, using other measures for processing, such as brain imaging techniques (e.g., positron emission tomography, magnetic resonance imaging), may allow the effects of target load to be localized in brain areas that are associated with either posterior visual perception areas (e.g., extra striate cortices, see Rees, Frith, & Lavie, 1997) or more anterior memory areas (e.g., prefrontal areas, see Fuster, 1993; Miller, Erickson, & Desimone, 1996).

For the moment, we conclude that perceptual load clearly plays an important role in visual selective attention. The present study demonstrated how NP from irrelevant distractors can crucially depend on the perceptual load involved in the relevant target processing. We conclude that although active mechanisms for ignoring, such as distractor inhibition, may be very important for ignoring irrelevant distractors in some cases (e.g., situations of low perceptual load), in some other cases (e.g., situations of high perceptual load), avoiding the distractors will not require any active mechanism at all. Rather, selective processing will naturally follow as a passive consequence of engaging all attentional capacity in a more demanding target task.

References

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of visual selective attention. *Annual Review of Neuroscience, 18,* 193–222.

Driver, J., & Tipper, S. P. (1989). On the nonselectivity of selective seeing: Contrasts between interference and priming in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 304–314.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87,* 272–300.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6,* 122–125.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non search task. *Perception & Psychophysics, 16,* 143–149.

Fisher, D. L. (1982). Limited-channel models of automatic detection: Capacity and scanning in visual search. *Psychological Review, 89,* 662–692.

Fox, E. (1994). Interference and negative priming from ignored distractors: The role of selection difficulty. *Perception and Psychophysics, 56,* 565–574.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2,* 145–173.

Fox, E. (1998). Perceptual grouping and visual selective attention. *Perception and Psychophysics, 60,* 1004–1021.

Fox, E. (2000). *The effect of target repetition on positive and negative identity priming.* Unpublished manuscript.

Fox, E., & de Fockert, J. (1998). Negative priming depends on prime-probe similarity: Evidence for episodic retrieval. *Psychonomic Bulletin and Review, 5,* 107–113.

Fuster, J. M. (1993). Memory cells in primate cortex and the activation of memory networks. In Ono, T., Squire, L. R., Raichle, M. E., Perrett, D. I., & Fukuda, M. (Eds.), *Brain mechanisms of perception and memory from neuron to behavior* (pp. 426–444). New York: Oxford University Press.

Gopher, D. (1992). The skill of attention control: Acquisition and execution of attention strategies. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance* (Vol. 14, pp. 187–204). Cambridge, MA: MIT Press.

Houghton, G., Tipper, S. P., Weaver, B., & Shore, D. I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition, 3,* 119–164.

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology, 37,* 43–75.

Johnston, W. A., & Heinz, S. P. (1978). Flexibility and capacity demands of attention. *Journal of Experimental Psychology: General, 107,* 420–435.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24,* 175–219.

Kane, M. J., May, C. P., Hasher, L., Rahhal, T., & Stoltzfus, E. R. (1997). Dual mechanisms of negative priming. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 632–650.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 451–468.

Lavie, N. (1997). Feature integration and selective attention: Response competition from unattended distractor features. *Perception & Psychophysics, 59,* 543–556.

Lavie, N. (2000). Selective attention and cognitive control: Dissociating attentional functions through different types of load. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII.* Cambridge, MA: MIT Press.

Lavie, N. (in press). The role of capacity limits in selective attention: Behavioural evidence and implications for neural activity. In J. Braun & C. Koch (Eds.), *Neural circuits of attention.* Cambridge, Massachusetts: MIT Press.

Lavie, N., & Cox, S. (1997). On the efficiency of attentional selection: Efficient visual search results in inefficient rejection of distraction. *Psychological Science, 8,* 395–398.

Lavie, N., & Hirst, S. (1999). *The role of working memory load in control of visual selective attention.* Unpublished manuscript.

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics, 56,* 183–197.

Malley, G. B., & Strayer, D. L. (1995). Effect of stimulus repetition on positive and negative identity priming. *Perception & Psychophysics, 57,* 657–667.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35–54.

Miller, E. K., Erickson, C. A., & Desimone, R. (1996). Neural mechanisms of visual working memory in prefrontal cortex of the macaque. *Journal of Neuroscience, 16,* 5154–5167.

Moore, C. M. (1994). Negative priming depends on probe-trial conflict: Where has all the inhibition gone? *Perception and Psychophysics, 56,* 133–147.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 80,* 214–255.

Neill, W. T. (1977). Inhibitory and facilitatory processes in attention. *Journal of Experimental Psychology: Human Perception & Performance, 3,* 444–450.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23,* 1291–1305.

Neill, W. T., & Valdes, L. A. (1996). Facilitatory and inhibitory aspects of attention. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 77–106). Washington, DC: American Psychological Association.

Neill, W. T., Valdes, L. A., & Terry, K. M. (1992). *Negative priming in target localization.* Paper presented at the 33rd annual meeting of the Psychonomic Society, St. Louis.

Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. In F. N. Dempster & C. J. Brainerd (Eds.), *New perspectives on interference and inhibition in cognition* (pp. 207–261). San Diego, CA: Academic Press.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology.* San Francisco: Freeman.

Neumann, E., Cherau, J. F., Hood, K. L., & Steinnagel, S. L. (1993). Does inhibition spread in a manner analogous to spreading activation? *Memory, 1,* 81–105.

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

Pylyshyn, Z., Burkell, J., Fisher, B., & Sears, C. (1994). Multiple parallel access in visual attention. *Canadian Journal of Experimental Psychology, 48,* 260–283.

Rees, G., Frith, C., & Lavie, N. (1997). Processing of irrelevant visual motion depends on the attentional load of an unrelated linguistic task. *Science, 278,* 1616–1619.

Schneider, W. (1988). Micro experimental laboratory: An integrated system for IBM PC compatibles. *Behaviour Research Methods, Instruments, and Computers, 20,* 206–217.

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

Tipper, S. P., & Milliken, B. (1996). Distinguishing between inhibition-based and episodic retrieval-based accounts of negative priming. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 77–106). Washington, DC: American Psychological Association.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review, 76,* 282–299.

Yantis, S., & Jones, E. (1991). Mechanisms of attentional selection: Temporally modulated priority tags. *Perception & Psychophysics, 50,* 166–178.

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