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Dilution, Not Load, Affects Distractor Processing

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Lavie and Tsal (1994) proposed that spare attentional capacity is allocated involuntarily to the processing of irrelevant stimuli, thereby enabling interference. Under this view, when task demands increase, spare capacity should decrease and distractor interference should decrease. In support, Lavie and Cox (1997) found that increasing perceptual load by increasing search set size decreased interference from an irrelevant distractor. In three experiments, we manipulated the cue set size (number of cued locations) independently of the display set size (number of letters presented). Increasing the display set size reduced distractor interference regardless of whether the additional letters were relevant to the task. In contrast, increasing the cue set size increased distractor interference. Both findings are inconsistent with the load explanation, but are consistent with a proposed two-stage dilution account.

Keywords: selective attention, load, distractor, interference

Successful completion of task goals requires the efficient deployment of attention to task-relevant information. In attempting to locate and process items relevant to the current task, irrelevant distracting items inevitably compete for attentional processing. For example, when attempting to read an internet article, there is typically a variety of advertisements designed to distract the reader from the current goal of reading the article. A key question, then, is whether the processing of stimuli irrelevant to our current goals can be reduced or even prevented.

According to filter theory or early selection theory (Broadbent, 1958), there is initial, involuntary, parallel processing of the physical characteristics of all stimuli. Based on the information derived from this initial analysis, a stimulus can be selected for further processing to determine its identity. This identification process is serial, with one stimulus processed at a time. Thus, according to strict early selection ideas, when the physical characteristics of task-relevant stimuli can be clearly distinguished from those of irrelevant stimuli, the irrelevant stimuli should not be processed to the level of identification. However, phenomena like the Stroop effect (Stroop, 1935; see MacLeod, 1991, for a review) and the flanker effect (Eriksen & Eriksen, 1974; see Eriksen, 1995, for a review) illustrate that there are situations in which we apparently cannot avoid processing the identity of irrelevant information. Because of such findings, late-selection theories (e.g., Deutsch & Deutsch, 1963; Duncan, 1980; Norman, 1968; Tipper, 1985) were proposed. These accounts hold that selection occurs later in the information processing stream such that there is an initial, involuntary, parallel processing of the identities of all stimuli. Thus, according to late-selection ideas, both the physical characteristics and the identities of all irrelevant stimuli will be processed. This early/late debate has played a central role in the study of attention for over 40 years (see Johnston & Dark, 1986; Lachter, Forster, & Ruthruff, 2004, for reviews).

The Load Account

Lavie and Tsal (1994; Lavie, 1995) put forth a load account to explain the extent to which irrelevant distractors are processed, an account that potentially could resolve the longstanding early selection versus late-selection debate. They argued that, if there is a clear physical distinction between relevant and irrelevant stimuli, observers can select relevant stimuli and prioritize them for identity processing. Thus, processing resources can be selectively allocated to the target. However, even when the observer is able to select and prioritize processing of the relevant stimuli, irrelevant stimuli may still be processed.

A critical feature of the Lavie and Tsal (1994) load account is that processing capacity is limited. If processing of the target requires less than the total available processing capacity, and if some irrelevant distractor is present in the display, then the spare capacity will be involuntarily allocated to the processing of the distractor. However, if processing of the relevant information exhausts capacity, then the distractor cannot be processed. This explanation is similar to early selection theories in that selection occurs early and identity processing is capacity limited. The key difference is in the allocation of spare capacity. Whereas early

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selection theories suggest that spare capacity need not be used, Lavie and Tsal suggest that spare capacity will be involuntarily deployed, including to the processing of unselected, irrelevant stimuli. In summary, their load account maintains that the load of the target task determines the spare capacity, which in turn determines the extent of processing of irrelevant distractors.

There have by now been numerous studies that have provided support for the Lavie and Tsal (1994) claim (e.g., Bavelier, Deruelle, & Proksch, 2000; D'Abrescia & Lavie, 2007; Forster & Lavie, 2007; Gibson & Bryant, 2008; Handy & Mangun, 2000; Kumada & Humphreys, 2002; Lavie, 1995; Lavie & Fox, 2000; Lavie, Lin, Zokaei, & Thoma, 2009; Maylor & Lavie, 1998; Paquet & Craig, 1997; Rees, Frith, & Lavie, 1997, 2001). For example, in an early demonstration, Lavie and Cox (1997, Experiment 2) combined a visual search task with a flanker task. On each trial, the participant searched a central array of heterogeneous letters for a target letter (X or N) while under instructions to ignore a peripheral task-irrelevant distractor (X or N or L). On congruent trials, the target and distractor were the same letter (both X or both N). On incongruent trials, the distractor was the alternative target letter (target X, distractor N, or vice versa). On neutral trials, the distractor was not part of the response set (distractor L).

Although congruent trials were included—to prevent a predictable relation between the target and distractor—the extent of distractor processing was indexed by distractor interference, defined as the difference in performance between incongruent and neutral trials. Load was operationally defined as search set size, with increasing set size assumed to increase load. Based on the load hypothesis, Lavie and Cox (1997) predicted that as load (set size) increased, capacity required to complete the search task would also increase, leaving fewer resources to process the irrelevant distractor. Consistent with this load account, they indeed found that as set size increased, distractor processing, as indexed by distractor interference, decreased.

A Dilution Account

As compelling as it is, the Lavie and Tsal (1994) load account is not the only possible explanation for decreased distractor interference with increased load. The alternative that we wish to consider here can be labeled a dilution account. This idea can be traced to earlier explanations of the reduction in Stroop interference that is caused by the addition of an irrelevant noncolor word. Kahneman and Chajczyk (1983) first reported this phenomenon in a version of the Stroop (1935) color-naming task in which a color bar appeared separately from a word. In naming the color of the bar, interference from an incongruent color word was reduced by about half when an irrelevant noncolor word was added to the display. This phenomenon has been termed Stroop dilution, and has been quite extensively documented (e.g., Brown, Gore, & Carr, 2002; Brown, Gore, & Pearson, 1998; Brown, Roos-Gilbert, & Carr, 1995; Cho, Lien, & Proctor, 2006; Mitterer, La Heij, & Van der Heijden, 2003; Roberts & Besner, 2005; Yee & Hunt, 1991).

There are interesting parallels in Stroop dilution to the Lavie and Cox (1997) research. Both procedures involve a target item and an irrelevant distractor, both have a condition in which an additional item or items are added to the display, and both show a reduction in distractor interference with the additional item(s). There is, however, a critical difference in the paradigms. In the Lavie and Cox procedure, apart from the distractor, the additional display items are the nontarget search letters, which increase the *relevant* perceptual load. In contrast, in the Kahneman and Chajczyk (1983) procedure, the additional display item (the irrelevant noncolor word) increases the *irrelevant* load without affecting the relevant load. Does the relevance of the load actually matter? According to the load account, relevance of the additional items does matter. Indeed, relevance is crucial: Increases in the relevant perceptual load are what cause reductions in spare capacity and hence in distractor interference. A key goal of the current research is to test this aspect of the load account by comparing the effect on distractor interference of adding relevant task items with that of adding irrelevant task items.

There are various explanations as to why dilution occurs. Consider again the capture account proposed by Kahneman and Chajczyk (1983). They suggested that only one word could be processed at a time. Thus, if an irrelevant color word is presented together with an irrelevant noncolor word, on average the color word would be processed on half of the trials, producing normal interference, and the noncolor word would be processed on the other half of the trials, producing no interference. Averaged across trials, distractor interference would be reduced by half relative to a condition without an irrelevant noncolor word. Brown et al. (1995) provided a modification to this explanation. They retained the idea of limited capacity but argued that on each trial the processing resources are shared between the color word and the noncolor word, both of which are irrelevant. Distractor interference on every trial would then be half of normal interference; of course, interference averaged across trials would then be reduced by half relative to a condition without the irrelevant noncolor word, resulting in the same dilution.

An alternative view of dilution suggests that crosstalk among early feature representations degrades the distractor representation, which reduces distractor interference (Brown et al., 1995; Bjork & Murray, 1977; Navon & Miller, 1987; but see Mitterer et al., 2003). As Brown et al. (1995, p. 1395) put it in the context of Stroop dilution: "Multiple patterns are processed in parallel. If any are color words, Stroop effects occur but are reduced because any color word's input to lexical memory is lower in quality than if a single color word were the only pattern." As the number of irrelevant items is increased, crosstalk will increase and distractor interference will be reduced.

To understand our dilution account, it is necessary to understand our conception of search processes. We follow Neisser (1967) and Hoffman (1979; see also Hoffman, Nelson, & Houck, 1983) in arguing that search is a two-stage process. In the first stage, there is a rapid, initial determination of the likely location of the target. Hoffman suggests that each search item is compared in parallel with memory, and that a resultant similarity measure is used to determine the likely target location. The location deemed to be the most likely one for the target is then selected for further processing in a second stage. In this limited-capacity second stage, attention is focused on—processing resources are allocated to—the stimulus at the most probable target location. Because the three existing dilution accounts all operate on a limited capacity stage, we assume that dilution operates during this second stage of focused attention.

How would the dilution account explain the results of Lavie and Cox (1997) described earlier? Upon presentation of the search display, the search letters are processed in parallel to determine the likely target location (first stage). Having identified the probable target location, that location is selected for further processing (second stage). Because attention is focused on one location, the load for this second stage is essentially one item. Furthermore, the nontarget search letters and the distractor are all considered irrelevant items for this second stage and are all subject to the effects of dilution. Note that the letter at the focus of attention might not be susceptible to dilution as it has been argued that focused attention prevents crosstalk from irrelevant items (Brown et al., 2002; Cheal & Gregory, 1997; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Shiu & Pashler, 1994). Now as set size is increased, dilution during the second stage will increase. This dilution will degrade the processing of all of the irrelevant letters but, most importantly, it will degrade the processing of the distractor letter, and thus decrease distractor interference.

Note that any of the dilution accounts that we have outlined could explain this dilution effect. Our goal here is not to provide evidence for a particular dilution account; rather, our goal is to determine whether the reduction in distractor interference with increased load is better explained by the Lavie and Tsal (1994) load account or by a dilution account. In sum, there are two explanations for why increases in search set size produce decreases in distractor interference: (1) the load hypothesis (Lavie & Tsal, 1994) which suggests that as relevant load increases, spare capacity decreases and hence distractor processing is reduced, and (2) the dilution hypothesis which suggests that as the relevant load increases, dilution increases, and processing of the irrelevant distractor is reduced.

The load account and the dilution account are similar in that both are limited-capacity resource models, but there is an important difference between them: The load hypothesis suggests that the relevance of the additional items matters—an increase in task-relevant items reduces spare capacity leaving fewer resources for processing the distractor. In contrast, the dilution hypothesis does not differentiate between relevant and irrelevant items. That is, the dilution effect is occurring during the focused attention stage (Stage 2) in which there is only one attended item. All other items, regardless of whether they were initially relevant, become irrelevant during the focused attention stage. Therefore, according to the dilution account, regardless of whether the additional items are task-relevant or task-irrelevant, dilution should increase, reducing distractor processing and hence distractor interference.

Our experiments were designed with two goals in mind. The first was empirical: to test whether the addition of relevant task items has the same impact on distractor interference as does the addition of irrelevant task items. The second was theoretical: to examine whether the load hypothesis or the dilution hypothesis provides a better account of distractor interference.

Experiment 1

To determine whether the relevance of additional task items is crucial for the load effect, we manipulated cue set size independently of display set size. Display set size refers to the number of letters presented; cue set size refers to the number of locations at which a target could appear, as specified by precues. Our task combines a cuing procedure (see, e.g., Palmer, Ames, & Lindsey, 1993) with a search and distractor procedure similar to that of Lavie and Cox (1997, Experiment 2)—a design that permits us to compare the effect on distractor interference of the addition of relevant versus irrelevant task items.

On each trial, there were two principal displays (see Figure 1). In the initial circular cue display with six locations, white plus signs indicated cued, relevant locations (locations where the target could appear on that trial), and gray plus signs indicated irrelevant locations (locations where the target could not appear on that trial). Cue set size was 2 or 6 cues, meaning that either 2 or 6 white plus signs were presented indicating relevant search locations. Following the cue display, a circular letter search display was presented that contained a target letter (X or N) and either one or five nontarget search letters. Display set size was, therefore, either 2 or 6 letters. For the 2-letter condition, the target and nontarget letter were presented at cued locations. For the 6-letter condition, the target was presented at a cued location, and the nontarget letters were presented at the remaining five locations. Additionally, at the center of the letter display, a task-irrelevant distractor (X or N or L) was presented, thereby creating congruent, incongruent, and neutral trials (see Beck & Lavie, 2005, for a similar use of a central distractor).

Method

Participants. Thirty-two University of Toronto at Scarborough undergraduate students participated in return for course credit or cash.

Apparatus. Stimuli were presented on a 14-inch VGA color monitor controlled by an IBM-compatible PC. The experimental program was written in QuickBasic 4.5 and used the routines provided by Graves and Bradley (1991) to achieve millisecond timing accuracy.

Design. There were three within-subject factors: cue set size (2, 6 cues), display set size (2, 6 letters), and target-flanker con-

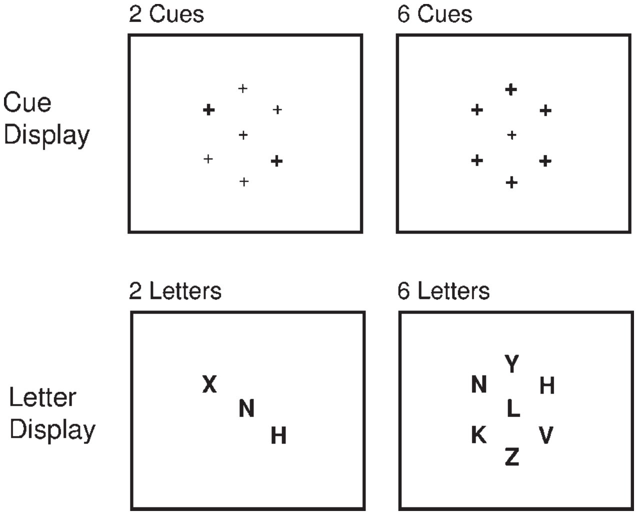

Figure 1. Experiment 1: Cue displays and letter displays for the cue set sizes of 2 and 6 cues and for the display set sizes of 2 and 6 letters. The smaller and lighter plus signs indicate uncued locations (actually presented in grey); the larger and darker plus signs indicate cued locations (actually presented in white). All plus signs were actually the same size. In the letter display, all letters were presented in white.

gruency (congruent, incongruent, neutral). Four blocks were formed by the factorial combination of cue set size and display set size. Block order was counterbalanced across participants. Each block began with 36 practice trials followed by 360 test trials (5 sets of 72 trials). Order of trials was randomized anew for each participant.

Procedure. Figure 1 illustrates the cue displays and letter displays presented on a trial. Each trial began with the presentation of a cue display that consisted of a central fixation plus sign, together with plus signs at each of the six potential letter locations. Each plus sign subtended 0.4° based on an approximate viewing distance of 50 cm. The six locations were 1.7° from the fixation center, and at angular positions of 0, 60, 120, 180, 240, and 300° from the fixation center. For the 2-cue condition, the plus signs at two locations (the target location and the opposite location) were presented in white (color 7). The target would always appear at one of the locations cued by the white plus signs. The plus signs at the remaining four locations were presented in gray (color 8). For the 6-cue condition, the plus signs at all six locations were presented in white, indicating that the target could appear at any of the six locations. The fixation plus sign was always presented in gray.

After 250 ms, the cue display was removed and the screen remained blank for 750 ms. The letter display was then presented, consisting of a target letter, 1 or 5 nontarget letters, and a distractor letter. All letters were .6° wide × .7° high. The target letter was selected randomly from the two possible targets (X, N), and was presented randomly at one of the cued locations. The distractor was presented at fixation. The target, nontarget(s), and distractor were all white. In the 2-letter condition, one nontarget letter, selected randomly from the set of five nontargets (H, K, V, Y, Z), was presented in the location opposite the target location. In the 6-letter condition, the five remaining search locations were filled with a random permutation of the five nontargets. The identity of the distractor (X, N, L) was randomized, producing three congruency conditions: (1) congruent—the distractor was the same as the target (both X or both N), (2) incongruent—the distractor was the other potential target letter (target X and distractor N, or vice versa), and (3) neutral—the distractor was the letter L.

The letter display remained on for 100 ms, at which point all display stimuli were removed and the computer waited for the participant to respond. The next trial began 500 ms after the response. Participants were instructed: (1) that a target was always present among the peripheral search letters, (2) that the target would always appear at one of the cued locations, (3) to ignore the central letter (the distractor) because it was not relevant to the current task, and (4) to respond as quickly yet as accurately as possible by pressing the X key with their left index finger for an X target, or the N key with their right index finger for an N target.

Results

A 2 × 2 × 2 repeated measures ANOVA was conducted on RTs as a function of cue set size (2, 6 cues), display set size (2, 6 letters), and congruency (neutral, incongruent). Only trials in which a correct response was provided were included in the RT analysis. The RTs are presented in Table 1. The three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 31) = 45.9$, $MS_e = 5{,}668$, $\eta = .60$, indicating that RTs were faster in the 2-cue condition (633 ms) than in the 6-cue condition (697 ms). The main effect of display set size was also significant, $F(1, 31) = 42.4$, $MS_e = 6{,}559$, $\eta = .58$, indicating that RTs were faster in the 2-letter condition (632 ms) than in the 6-letter condition (698 ms). Therefore, we have evidence that task performance decreased with both cue set size and display set size. Furthermore, cue set size and display set size interacted, $F(1, 31) = 27.7$, $MS_e = 4{,}643$, $\eta = .47$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (21 ± 11 ms) than for the 6-cue condition (111 ± 36 ms).[1] This means that the addition of 4 letters to the display slowed overall responding by 21 ms when the added letters were presented in irrelevant locations (2-cue, 6-letter vs. 2-cue, 2-letter condition) but by 111 ms when the added letters were presented in relevant locations (6-cue, 6-letter vs. 6-cue, 2-letter condition). Because we assume that overall RT is an indicator of load, these data suggest, perhaps not surprisingly, that increasing the relevant perceptual load is more demanding than increasing the irrelevant perceptual load. The main effect of congruency was also significant, $F(1, 31) = 59.6$, $MS_e = 1{,}277$, $\eta = .66$; incongruent RTs (683 ms) were slower than neutral RTs (648 ms), demonstrating interference from the distractor.

Display set size interacted with congruency, $F(1, 31) = 11.4$, $MS_e = 555$, $\eta = .27$, reflecting the greater interference caused by distractors in the 2-letter condition (45 ± 13 ms) than in the 6-letter condition (25 ± 8 ms). Cue set size also interacted with congruency, $F(1, 31) = 4.1$, $MS_e = 474$, $p = .051$, $\eta = 12$ (marginal), but in the opposite direction, suggesting that there was *less* distractor interference in the 2-cue condition (29 ± 12 ms) than in the 6-cue condition (40 ± 9 ms).

The same ANOVA was conducted on error percentages, shown in Table 2. The three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 31) = 45.5$, $MS_e = 41.9$, $\eta = .60$, indicating that fewer errors were made in the 2-cue condition (6.7%) than in the 6-cue condition (12.1%). The main effect of display set size was also significant, $F(1, 31) = 85.8$, $MS_e = 49.1$, $\eta = .74$, indicating that fewer errors were made in the 2-letter condition (5.3%) than in the 6-letter condition (13.5%). Therefore, we have further evidence that each of the set size manipulations was effective in increasing task demands. Furthermore, cue set size and display set size interacted, $F(1, 31) = 48.1$, $MS_e = 36.8$, $\eta = .61$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (2.8%) than for the 6-cue condition (13.4%). The main effect of congruency was significant, $F(1, 31) = 10.2$, $MS_e = 11.1$, $\eta = .25$, with more errors in the incongruent condition (10.1%) than in the neutral condition (8.7%). Neither the interaction of cue set size with congruency nor that of display set size with congruency was significant, both $F\text{s} < 1$.

Discussion

Effect of display set size. An increase in display set size produced a decrease in distractor interference. Critically, however, it did not matter whether the additional letters were presented in

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[1] Here and subsequently, we report the 95% confidence intervals for the associated means.

Table 1

Experiment 1: Mean RTs as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency (C = Congruent; I = Incongruent; N = Neutral); Interference Is Defined as Incongruent RT Minus Neutral RT

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
2 letters	605 (14)	642 (17)	603 (13)	39	615 (13)	667 (15)	617 (13)	50
6 letters	633 (13)	653 (17)	634 (14)	19	740 (22)	768 (23)	737 (22)	31

Note. Standard errors are shown in parentheses below their respective means.

relevant or in irrelevant search locations: The reduction in interference with increasing display set size was of a virtually identical magnitude—20 ms for the 2-cue condition and 19 ms for the 6-cue condition. This finding of the same reduction in interference with increasing display set size for both cue set sizes is inconsistent with the load account (Lavie & Tsal, 1994). To see this, collapse across congruency: The addition of 4 letters to the display slowed overall responding by 21 ms when the added letters were presented in irrelevant locations (2-cue, 6-letter vs. 2-cue, 2-letter condition) but by 111 ms when the added letters were presented in relevant locations (6-cue, 6-letter vs. 6-cue, 2-letter condition). If relevant perceptual load alone was driving the decrease in interference with increasing display set size, then, according to the load hypothesis, this reduction should have been considerably larger when relevant letters were added than when irrelevant letters were added. Clearly, this was not the case.

Although inconsistent with the load hypothesis, these findings are consistent with the dilution hypothesis. The dilution hypothesis suggests that the addition of 4 letters should degrade distractor processing and consequently reduce distractor interference. Moreover, the magnitude of the reduction in distractor interference should be the same regardless of whether the four additional letters are in relevant (cued) or irrelevant locations. This is exactly what we found.

Effect of cue set size. In contrast to the finding that increasing the display set size reduced distractor interference, we found that increasing the cue set size actually increased distractor interference. Consider a comparison of the 2-cue, 6-letter condition with the 6-cue, 6-letter condition. The latter condition has four additional search letters presented in relevant locations. Clearly, the relevant perceptual load has increased with the addition of these 4 letters in relevant, cued locations. However, contrary to the load hypothesis (Lavie & Tsal, 1994), which predicts that this increase in relevant perceptual load should lead to a decrease in distractor interference, we found that distractor interference actually increased. Thus, the load account does not generalize to a manipulation of number of relevant locations.

The two-stage dilution account does explain the cue set size effect on distractor interference. During the first parallel processing stage, all items are processed in parallel in an attempt to determine the most probable target location. We propose that increases in the cue set size increase uncertainty regarding the target location or, in other words, increase the decision noise regarding the target location (for more on decision noise, see Palmer, 1994, 1995; Palmer, Ames, & Lindsey, 1993). This increased uncertainty slows the determination of the most probable target location, which increases the length of time spent in this parallel processing stage. Increases in the time spent in this parallel processing stage should increase distractor processing and distractor interference. In summary, the increase in cue set size increases decision noise, which increases the time spent in the first parallel processing stage, which should increase distractor processing and distractor interference.

The opposite influences of display set size and cue set size on distractor interference observed here are inconsistent with the load hypothesis (Lavie & Tsal, 1994), but are consistent with the two-stage dilution hypothesis. These results thus imply that the reduced interference found by Lavie and Cox (1997) with increases in set size may not have been caused by the increase in relevant perceptual load and the resultant reduced spare capacity.

Table 2

Experiment 1: Mean Error Percentages as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency (C = Congruent; I = Incongruent; N = Neutral); Interference Is Defined as Incongruent Error Percentage Minus Neutral Error Percentage

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
2 letters	4.6 (0.5)	6.0 (0.6)	4.5 (0.5)	1.5	4.7 (0.5)	6.0 (0.7)	4.9 (0.5)	2.1
6 letters	7.4 (0.9)	8.6 (0.9)	7.6 (0.7)	1.0	18.1 (1.7)	19.6 (1.9)	18.0 (1.9)	1.6

Note. Standard errors are shown in parentheses below their respective means.

Rather, the reduction in distractor interference may have been caused by a dilution of distractor processing when more nontarget items were present.

Experiment 2

One concern that might be raised regarding Experiment 1 is that although the distractor was presented in a distinct location, the fact that the distractor was presented in the same color as the target and nontargets may have made the initial selection process more difficult. It is important to ensure that our Experiment 1 findings regarding the combined influences of cue set size and display set size are not contingent on having a distractor that is not clearly distinct from the search letters. Therefore, in Experiment 2, we made the distractor more distinct by presenting it in both a unique location and a unique color. In Experiment 2A, we presented the cue set size and display set size conditions in separate blocks of trials. To eliminate possible strategy differences between set size conditions that might arise from the blocking of these conditions—and to provide a replication—we randomly mixed trials for the cue set size and display set size conditions in Experiment 2B.

Experiment 2A

In Experiment 2A, the distractor was made more distinct by presenting it in both a unique location and a unique color. Set size conditions were blocked as in Experiment 1.

Method. Twenty-four University of Toronto at Scarborough undergraduate students participated in return for course credit or cash. The apparatus, design, and procedure were identical to those of Experiment 1 with two exceptions: (1) the plus signs indicating the cued locations were presented in yellow (color 14), and (2) the target and nontargets were presented in green (color 2). The distractor was again presented in white (color 7).

Results. The RTs for both Experiments 2A and 2B are presented in Table 3. For both experiments, only trials in which a correct response was provided were included in the RT analyses. Through comparison with Table 1, it is clear that the findings of Experiment 2A using a more distinct distractor closely replicated those of Experiment 1. A 2 × 2 × 2 ANOVA was conducted on RTs in Experiment 2A as a function of cue set size (2, 6 cues), display set size (2, 6 letters), and congruency (neutral, incongruent). The three-way interaction was not significant, $F(1, 23) = 1.1$, $MS_e = 964$. The main effect of cue set size was significant, $F(1, 23) = 38.7$, $MS_e = 4{,}381$, $\eta = .63$, indicating that RTs were faster in the 2-cue condition (631 ms) than in the 6-cue condition (691 ms). The main effect of display set size was also significant, $F(1, 23) = 40.2$, $MS_e = 5{,}382$, $\eta = .64$, indicating that RTs were faster in the 2-letter condition (628 ms) than in the 6-letter condition (695 ms). Therefore, we have evidence that task performance decreased with increases in both cue set size and display set size. Furthermore, cue set size and display set size interacted, $F(1, 23) = 10.4$, $MS_e = 4{,}859$, $\eta = .31$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (35 ± 15 ms) than for the 6-cue condition (100 ± 38 ms), with magnitudes similar to those in Experiment 1. The main effect of congruency was also significant, $F(1, 23) = 30.4$, $MS_e = 701$, $\eta = .57$; incongruent RTs (672 ms) were slower than neutral RTs (651 ms).

Display set size interacted with congruency, $F(1, 23) = 17.0$, $MS_e = 382$, $\eta = .42$, reflecting the greater interference by distractors in the 2-letter condition (33 ± 9 ms) than in the 6-letter condition (9 ± 9 ms). Cue set size also interacted with congruency, $F(1, 23) = 9.7$, $MS_e = 366$, $\eta = .30$, but in the opposite direction: There was *less* interference from distractors in the 2-cue condition (13 ± 7 ms) than in the 6-cue condition (30 ± 11 ms).

The error percentages for Experiments 2A and 2B are presented in Table 4. The same ANOVA was conducted on error percentages. For Experiment 2A, the three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 23) = 37.7$, $MS_e = 38.1$, $\eta = .62$, indicating that fewer errors were made in the 2-cue condition (10.8%) than in the 6-cue condition (16.3%). The main effect of display set size was also significant, $F(1, 23) = 73.2$, $MS_e = 56.8$, $\eta = .76$, indicating that fewer errors were made in the 2-letter condition (8.9%) than in the 6-letter condition (18.2%). Therefore, we have converging evidence on the two dependent measures that each of the set size manipulations was effective in increasing task demands. Furthermore, cue set size and display set size interacted, $F(1, 23) = 31.0$, $MS_e = 46.3$, $\eta = .57$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (3.8%) than for the 6-cue condition (14.8%). The main effect of congruency was significant, $F(1, 23) = 9.1$, $MS_e =$

Table 3
Experiment 2: Mean RTs as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency (C = Congruent; I = Incongruent; N = Neutral); Interference Is Defined as Incongruent RT Minus Neutral RT

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
Experiment 2A								
2 letters	596 (14)	624 (15)	604 (14)	20	615 (16)	664 (18)	618 (14)	46
6 letters	650 (17)	652 (17)	646 (17)	6	732 (24)	747 (27)	734 (24)	13
Experiment 2B								
2 letters	596 (17)	618 (18)	601 (17)	17	635 (20)	683 (23)	631 (17)	52
6 letters	646 (21)	657 (20)	651 (21)	6	802 (29)	830 (33)	807 (29)	23

Note. Standard errors are shown in parentheses below their respective means.

Table 4

Experiment 2: Mean Error Percentages as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency (C = Congruent; I = Incongruent; N = Neutral); Interference Is Defined as Incongruent Error Percentage Minus Neutral Error Percentage

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
Experiment 2A								
2 letters	7.5 (0.9)	10.1 (1.1)	7.6 (1.1)	2.5	6.7 (1.0)	10.2 (1.2)	7.6 (0.9)	2.6
6 letters	5.9 (1.2)	6.5 (1.3)	5.9 (1.4)	0.6	5.7 (1.2)	7.4 (1.5)	5.7 (1.1)	1.7
Experiment 2B								
2 letters	11.2 (1.6)	12.7 (1.6)	12.8 (1.8)	−0.1	22.1 (2.0)	23.7 (2.0)	23.6 (2.2)	0.1
6 letters	9.2 (2.0)	10.0 (2.0)	8.6 (2.2)	1.4	20.7 (2.5)	23.0 (2.4)	23.1 (2.7)	−0.1

Note. Standard errors are shown in parentheses below their respective means.

8.7, $\eta = .28$, with more errors in the incongruent condition (14.2%) than in the neutral condition (12.9%). Display set size interacted with congruency, $F(1, 23) = 7.1$, $MS_e = 11.2$, $\eta = .24$, reflecting the greater interference by distractors in the 2-letter condition (2.6%) than in the 6-letter condition (0.0%). The interaction of cue set size with congruency was not significant, $F < 1$.

Experiment 2B

In the previous experiments, set size conditions were blocked. To eliminate concerns about possible strategy differences between set size conditions that might arise from blocking, in Experiment 2B we randomly mixed trials for the cue set size and display set size conditions. Again, the distractor was distinct both in location and in color.

Method. Sixteen students from the same pool participated in return for course credit or cash. The apparatus, design, and procedure were identical to those of Experiment 2A except that relevant and display set size conditions were mixed rather than blocked. As a result, there was now a single practice block consisting of 144 practice trials (2 sets of 72 trials). The 1440 test trials (20 sets of 72 trials) consisted of 360 trials for each of the four conditions formed by the factorial combination of cue set size and display set size. The order of trials within the practice block and the test trial blocks was randomized anew for each participant.

Results. A 2 × 2 × 2 repeated measures ANOVA was conducted on RTs as a function of cue set size (2, 6 cues), display set size (2, 6 letters), and congruency (neutral, incongruent). The three-way interaction was not significant, $F(1, 15) = 1.6$, $MS_e = 417$. The main effect of cue set size was significant, $F(1, 15) = 95.5$, $MS_e = 3{,}779$, $\eta = .86$, indicating that RTs were substantially faster in the 2-cue condition (632 ms) than in the 6-cue condition (738 ms). The main effect of display set size was also significant, $F(1, 15) = 80.8$, $MS_e = 4{,}188$, $\eta = .84$, indicating that RTs were substantially faster in the 2-letter condition (633 ms) than in the 6-letter condition (736 ms). Therefore, we again have evidence that task performance decreased with increases in both cue set size and display set size. Furthermore, cue set size and display set size interacted, $F(1, 15) = 55.7$, $MS_e = 1{,}967$, $\eta = .79$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (45 ± 15 ms) than for the 6-cue condition (161 ± 39 ms). The main effect of congruency was also significant, $F(1, 15) = 13.9$, $MS_e = 1{,}378$, $\eta = .48$; incongruent RTs (697 ms) were slower than neutral RTs (672 ms).

Display set size interacted with congruency, $F(1, 15) = 5.5$, $MS_e = 547$, $\eta = .27$, reflecting the greater interference by distractors in the 2-letter condition (34 ± 14 ms) than in the 6-letter condition (14 ± 17 ms). Cue set size also interacted with congruency, $F(1, 15) = 9.6$, $MS_e = 572$, $\eta = .39$, but in the opposite direction: There was *less* interference from distractors in the 2-cue condition (11 ± 8 ms) than in the 6-cue condition (37 ± 22 ms).

The same ANOVA was conducted on error percentages. The three-way interaction was not significant, $F(1, 15) = 1.8$, $MS_e = 7.9$. The main effect of cue set size was significant, $F(1, 15) = 56.1$, $MS_e = 28.2$, $\eta = .79$, indicating that fewer errors were made in the 2-cue condition (7.8%) than in the 6-cue condition (14.8%). The main effect of display set size was also significant, $F(1, 15) = 84.8$, $MS_e = 36.4$, $\eta = .85$, indicating that fewer errors were made in the 2-letter condition (6.4%) than in the 6-letter condition (16.2%). Therefore, we have further converging evidence that each of the set size manipulations was effective in increasing task demands. Furthermore, cue set size and display set size interacted, $F(1, 15) = 83.4$, $MS_e = 17.4$, $\eta = .84$, showing that the effect of the display set size manipulation (6-letter minus 2-letter condition) was smaller for the 2-cue condition (3.1%) than for the 6-cue condition (16.6%). The main effect of congruency was not significant, $F(1, 15) = 1.6$, $MS_e = 15.6$. Neither the interaction of cue set size with congruency nor the interaction of display set size with congruency was significant, both Fs < 1.

Discussion. Experiments 2A and 2B confirm the results of Experiment 1, providing further support for the dilution hypothesis. When increased, both cue set size and display set size slowed overall responding. However, the effects of these two set size manipulations on distractor interference were opposite: Increasing display set size led to reduced interference whereas increasing cue set size led to increased interference. Experiments 2A and 2B further clarify the picture presented in Experiment 1 in three ways. First, they provide very consistent replications. Second, it is now clear that the color distinctiveness of the distractor with respect to the letter display to be searched is not critical: The effects are the same whether the distractor is less distinctive (same color but spatially distinct, Experiment 1) or more distinctive (both color distinct and spatially distinct, Experiment 2). And third, they demonstrate that the pattern of data in Experiment 1 is not restricted to cases where the set size conditions are presented in separate blocks: Mixing all of the trials here resulted in almost exactly the same overall data pattern.

There was, however, one trend in both Experiments 2A and 2B that, although not significant, could be taken as support for the Lavie and Tsal (1994) load hypothesis. Unlike in Experiment 1, there appeared to be a larger reduction in interference with the addition of four relevant letters (6-cue, 6-letter vs. 6-cue 2-letter condition) (Experiment 2A, 33 ms; Experiment 2B, 29 ms) compared to the addition of four irrelevant letters (2-cue, 6-letter vs. 2-cue, 2-letter condition) (Experiment 2A, 14 ms; Experiment 2B, 11 ms). The load hypothesis might be able to account for this result. Consider that the addition of the four relevant letters adds a significantly greater relevant perceptual load than does the addition of the four irrelevant letters: In Experiment 2A, the addition of four relevant letters (6-cue, 6-letter vs. 6-cue, 2-letter condition) increased RTs 100 ms, whereas the addition of four irrelevant letters (2-cue, 6-letter vs. 2-cue, 2-letter condition) increased RTs 35 ms. In Experiment 2B, the respective costs were 161 and 45 ms. If relevant perceptual load was driving the decrease in interference then, according to the load hypothesis, the reduction in interference with increasing display set size should have been larger in the 6-cue condition than in the 2-cue condition, which is what the previously described trend suggests.

Note, however, that the addition of four relevant letters (6-cue, 6-letter vs. 6-cue, 2 letter condition) produced reductions in interference of 33 and 29 ms for Experiments 2A and 2B, respectively. However, interference in the 2-cue, 2-letter condition was only 20 ms for Experiment 2A and 17 ms for Experiment 2B. It obviously is difficult to achieve a reduction in interference of either 33 or 29 ms with the addition of four irrelevant letters (2-cue, 6-letter vs. 2-cue, 2-letter condition) when interference for the 2-cue, 2-letter condition is not sufficiently above zero to achieve the needed reduction—in essence, when a floor effect exists. Thus, the reason that the reduction in distractor interference observed with the addition of irrelevant letters was less than that observed with the addition of relevant letters may be that interference in the 2-cue, 2-letter condition was simply too small.

To test this hypothesis, we combined the data of Experiments 2A and 2B, and performed a median split on the overall level of interference. If we failed to find a similar reduction in interference for the addition of relevant and irrelevant letters because interference was simply too low in the 2-cue, 2-letter condition, then interference should be sufficiently high for our high interference participants to exhibit a similar reduction in interference with the addition of relevant and irrelevant letters, as in Experiment 1. If the load hypothesis is correct, however, then high interference participants should again exhibit a greater reduction in interference with the addition of relevant letters than with the addition of irrelevant letters.

Interference results for the high interference participants were as follows: 2-cue, 2-letter condition—32 ms; 2-cue, 6-letter condition—11 ms; 6-cue, 2-letter condition—67 ms; 6-cue, 6-letter condition—45 ms. For participants with high levels of interference, the reduction in interference was of a virtually identical magnitude both for the addition of irrelevant letters (21 ms) and for the addition of relevant letters (22 ms). This result is inconsistent with the load hypothesis (Lavie & Tsal, 1994). It is, however, consistent with the findings from Experiment 1 and with the dilution hypothesis which predicts that, regardless of the impact of the letters on the relevant perceptual load, the extent of distractor processing and therefore of interference will decrease with increases in display set size.

In summary, Experiments 2A and 2B support the conclusion that the reduced interference found by Lavie and Cox (1997) with increases in display set size was caused by a dilution of distractor processing, not by the increase in relevant perceptual load and a corresponding reduction in spare capacity.

Experiment 3

Although it is clear in Experiments 1 and 2 that, as the cue set size increased, task performance decreased, we cannot definitively conclude from this that the allocation of attention to two locations requires fewer resources than does the allocation of attention to all six locations. In the 6-cue condition, all six search locations were precued, the intent being to have participants attend to all six locations. We expected that this would constitute a greater load than the 2-cue condition. However, there remains the possibility that the selective allocation of attention to two locations actually requires more processing resources than does not selectively allocating attention to any subset of the six locations. Basically, the 6-cue precue could either be used to allocate attention to all six locations or to indicate that the selective allocation of attention is not necessary. Therefore, in Experiment 3, we increased the number of locations to eight and added an additional display set size with 8 letters presented. This meant that the 6-cue precue now provided useful information to the participant, so that attention could be allocated to the six locations precued, knowing that the target would not appear at either of the two remaining uncued locations. Experiment 3A presented the search letters at the same eccentricity as the prior experiments. In Experiment 3B, we spread the letters out to a greater eccentricity to reduce any possible concern regarding lateral masking of the distractor.

Experiment 3A

In Experiment 3A, the number of locations was increased to eight, so that the number of letters presented could be 2, 6, or 8. Although the cued location conditions were unchanged—either 2 or 6 locations were precued—the cues for the 6-cue condition could now be used to selectively guide the allocation of attention.

Method.

Participants. Thirty-two University of Toronto at Scarborough undergraduate students participated in return for course credit or cash.

Apparatus. The apparatus was identical to that of the previous experiments.

Design. There were three within-subject factors: cue set size (2, 6 cues), display set size (2, 6, 8 letters), and target-flanker congruency (congruent, incongruent, neutral). There were 144 practice trials (2 sets of 72 trials) followed by 1,440 test trials (20 sets of 72 trials) that consisted of 240 trials for each of the six conditions formed by the factorial combination of cue set size and display set size. Trials for the six conditions were mixed. The order of trials was randomized anew for each participant.

Procedure. Figure 2 illustrates the cue displays and letter displays that were presented on a trial. The procedure was identical to that of Experiment 2A with the following exceptions: (1) the cue display consisted of a central fixation plus sign, and a plus sign at each of the *eight* potential letter locations. The eight locations were 2.3° from the fixation center (based on an approximate viewing distance of 50 cm), and at angular positions of 0, 45, 90, 135, 180, 225, 270, and 315° from the fixation center. (2) For the 6-cue condition, the six locations that were precued (by white plus signs) always consisted of three adjacent locations plus the opposite three adjacent locations to maintain a symmetrical cue presentation. The target letter was equally likely to appear at any of the six cued locations. (3) The letter display consisted of a target letter, a distractor letter, and 1, 5, or 7 nontarget letters. The set of nontarget letters was increased to H, K, V, Y, Z, W, and E.

Results. The RTs for both Experiments 3A and 3B are presented in Table 5. For both experiments, only trials in which a correct response was provided were included in the RT analyses. A 2 × 3 × 2 repeated measures ANOVA was conducted on RTs as a function of cue set size (2, 6 cues), display set size (2, 6, 8 letters), and congruency (neutral, incongruent). For Experiment 3A, the three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 31) = 75.0$, $MS_e = 15{,}212$, $\eta = .71$, indicating that RTs were substantially faster in the 2-cue condition (672 ms) than in the 6-cue condition (781 ms). The main effect of display set size was also significant, $F(2, 62) = 54.6$, $MS_e = 4{,}920$, $\eta = .64$; RTs were faster in the 2-letter condition (674 ms) than in the 6-letter condition (751 ms), $F(1, 31) = 71.7$, $MS_e = 10{,}772$, $\eta = .71$, but RTs in the 6-letter and 8-letter (755 ms) conditions did not differ, $F < 1$. This provides evidence that an increase in both cue set size and display set size produced a task performance cost, but that the 8-letter condition produced no significantly greater cost relative to the 6-letter condition. Cue set size and display set size interacted, $F(2, 62) = 21.6$, $MS_e = 2{,}732$, $\eta = .41$. Linear contrasts indicated that this interaction existed within the 2-letter and 6-letter conditions. That is, the effect of the cue set size manipulation (6-cue minus 2-cue condition) was smaller for the 2-letter condition (60 ± 19 ms) than for the 6-letter condition (128 ± 31 ms), $F(1, 31) = 26.3$, $MS_e = 5{,}682$, $\eta = .46$, but the effect of the cue set size manipulation did not differ for the 6-letter and 8-letter (139 ± 37 ms) conditions, $F(1, 31) = 1.9$, $MS_e = 1{,}973$. The main effect of congruency was also significant, $F(1, 31) = 21.5$, $MS_e = 3{,}397$, $\eta = .41$; incongruent RTs (740 ms) were longer than neutral RTs (713 ms).

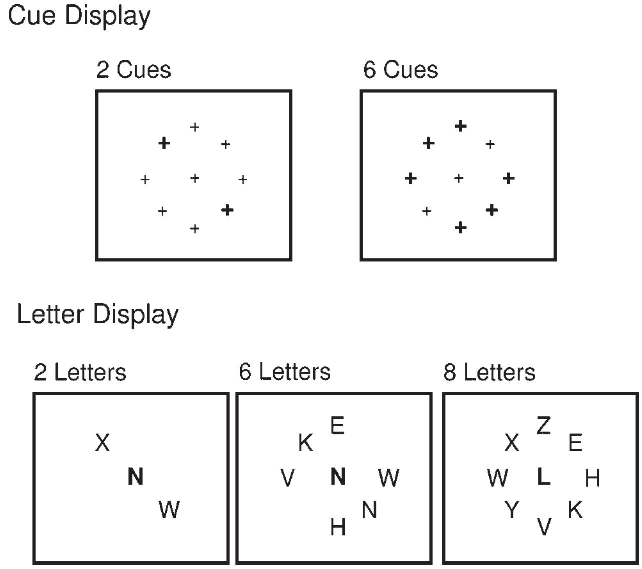

Figure 2. Experiment 3: Cue displays and letter displays for the cue set sizes of 2 and 6 cues and for the display set sizes of 2, 6, and 8 letters. For the cue display, smaller and lighter plus signs indicate uncued locations (actually presented in grey); larger and darker plus signs indicate cued locations (actually presented in yellow). All plus signs were actually the same size. In the letter display, the target and nontarget letters shown in lighter letters were actually presented in green; the distractor shown in bold was actually presented in white.

Display set size interacted with congruency, $F(2, 62) = 7.5$, $MS_e = 1{,}382$, $\eta = .20$. Linear contrasts indicated that this interaction existed within the 2-letter and 6-letter conditions. That is, interference was greater in the 2-letter condition (47 ± 13 ms) than in the 6-letter condition (23 ± 18 ms), $F(1, 31) = 6.8$, $MS_e = 2{,}674$, $\eta = .18$, but interference did not differ reliably for the 6-letter and 8-letter (12 ± 14 ms) conditions, $F(1, 31) = 1.3$, $MS_e = 3{,}288$. Cue set size also interacted with congruency, $F(1, 31) = 5.4$, $MS_e = 1{,}029$, $\eta = .15$, but in the opposite direction: There was *less* interference from distractors in the 2-cue condition (20 ± 10 ms) than in the 6-cue condition (36 ± 15 ms).

The error percentages for both Experiments 3A and 3B are presented in Table 6. The same ANOVA was conducted on error percentages. For Experiment 3A, the three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 31) = 184.1$, $MS_e = 47.7$, $\eta = .86$, indicating that fewer errors were made in the 2-cue condition (10.2%) than in the 6-cue condition (19.8%). The main effect of display set size was also significant, $F(2, 62) = 157.9$, $MS_e = 26.9$, $\eta = .84$. Contrasts indicated that fewer errors were made in the 2-letter condition (8.5%) than in the 6-letter condition (17.0%), $F(1, 31) = 161.3$, $MS_e = 57.7$, $\eta = .84$, and that fewer errors were made in the 6-letter condition than in the 8-letter (19.5%) condition, $F(1, 31) = 29.5$, $MS_e = 26.0$, $\eta = .49$. This is evidence that an increase in each of the set size dimensions produced a task performance cost; in particular, there was a significant additional cost for the 8-letter over the 6-letter condition that was not reliable in the RTs. Cue set size and display set size interacted, $F(2, 62) = 83.9$, $MS_e = 20.7$, $\eta = .73$. The effect of the cue set size manipulation (6-cue minus 2-cue condition) was smaller for the 2-letter condition (1.2%) than for the 6-letter condition (12.3%), $F(1, 31) = 79.8$, $MS_e = 49.9$, $\eta = .72$, and smaller for the 6-letter condition than for the 8-letter condition (15.2%), $F(1, 31) = 9.0$, $MS_e = 27.1$, $\eta = .22$. The main effect of congruency was also significant, $F(1, 31) = 36.2$, $MS_e = 14.4$, $\eta = .54$; more errors were made in the incongruent condition (16.2%) than in the neutral condition (13.9%).

The interaction of display set size and congruency was not significant, $F < 1$. However, cue set size interacted with congruency, $F(1, 31) = 7.6$, $MS_e = 11.5$, $\eta = .20$, indicating that there was less interference from distractors in the 2-cue condition (1.3%) than in the 6-cue condition (3.3%), confirming the RT finding that distractor interference increases with cue set size.

Table 5

Experiment 3: Mean RTs as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency; Interference Is Defined as Incongruent RT Minus Neutral RT

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
Experiment 3A								
2 letters	631 (14)	662 (15)	625 (12)	37	674 (18)	733 (18)	675 (16)	58
6 letters	673 (16)	696 (14)	679 (16)	17	811 (21)	831 (27)	800 (20)	31
8 letters	677 (16)	689 (14)	682 (14)	7	813 (25)	833 (27)	816 (23)	17
Experiment 3B								
2 letters	635 (16)	668 (18)	627 (15)	41	677 (21)	738 (21)	678 (20)	60
6 letters	673 (18)	692 (17)	678 (19)	14	817 (25)	840 (32)	803 (24)	37
8 letters	675 (19)	687 (17)	681 (17)	6	819 (30)	835 (30)	818 (26)	17

Note. Standard errors are shown in parentheses below their respective means.

In summary, the findings of Experiment 3A provide evidence that the effect of cue set size on distractor processing found in Experiments 1 and 2 also holds in a situation in which the cues for the 6-cue condition could be used to selectively guide the allocation of attention.

Experiment 3B

An alternative explanation for the decrease in distractor interference with increasing perceptual load is that, as a consequence of the relatively close spacing of the letters, each additional letter produces additional lateral masking of the distractor. To eliminate the possibility of lateral masking effects, in Experiment 3B, the eccentricity of the search letters was increased to 5°, more than doubling the eccentricity used in Experiment 3A.

Method. Twenty-six students from the same pool participated in return for course credit or cash. The apparatus, design, and procedure were identical to those of Experiment 3A except that the search letters were presented at 5° from center, instead of 2.3° from center.

Results. A 2 × 3 × 2 ANOVA was conducted on RTs as a function of cue set size (2, 6 cues), display set size (2, 6, 8 letters), and congruency (neutral, incongruent). The three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 25) = 65.0$, $MS_e = 15{,}455$, $\eta = .72$, indicating that RTs were considerably faster in the 2-cue condition (672 ms) than in the 6-cue condition (786 ms). The main effect of display set size was also significant, $F(2, 50) = 37.9$, $MS_e = 5{,}352$, $\eta = .60$. Contrasts indicated that RTs were faster in the 2-letter condition (678 ms) than in the 6-letter condition (753 ms), $F(1, 25) = 50.2$, $MS_e = 11{,}773$, $\eta = .67$, but that those in the 6-letter and 8-letter (755 ms) conditions did not differ, $F < 1$. This is evidence that increases in both cue set size and display set size produced task performance costs, although the 8-letter condition produced no significant additional cost relative to the 6-letter condition.

Cue set size and display set size interacted, $F(2, 50) = 18.9$, $MS_e = 2{,}888$, $\eta = .43$. Contrasts indicated that this interaction existed within the 2-letter and 6-letter conditions. That is, the effect of the cue set size manipulation (6-cue minus 2-cue condition) was smaller for the 2-letter condition (61 ± 23 ms) than for the 6-letter condition (137 ± 36 ms), $F(1, 25) = 24.3$, $MS_e = 6{,}238$, $\eta = .49$, but the effect of the cue set size manipulation did not differ for the 6-letter and 8-letter (143 ± 40 ms) conditions,

Table 6

Experiment 3: Mean Error Percentages as a Function of Cue Set Size, Display Set Size, and Target-Distractor Congruency; Interference Is Defined as Incongruent Minus Neutral Error Percentage

	Cue set size							
	2 cues				6 cues			
Display set size	C	I	N	Interference	C	I	N	Interference
Experiment 3A								
2 letters	6.5 (1.1)	8.4 (1.3)	7.4 (1.2)	1.0	6.7 (1.1)	10.7 (1.5)	7.6 (1.5)	3.1
6 letters	10.4 (1.4)	11.8 (1.4)	9.9 (1.5)	1.9	21.2 (1.5)	25.3 (1.9)	21.2 (1.8)	4.1
8 letters	11.2 (1.4)	12.6 (1.5)	11.3 (1.3)	1.3	25.8 (1.7)	28.4 (1.9)	25.7 (1.8)	2.7
Experiment 3B								
2 letters	6.9 (1.3)	9.0 (1.5)	8.1 (1.4)	0.9	7.4 (1.3)	11.2 (1.7)	8.3 (1.8)	2.9
6 letters	11.0 (1.7)	12.3 (1.7)	10.7 (1.8)	1.6	22.0 (1.6)	26.5 (2.1)	22.7 (2.0)	3.8
8 letters	11.4 (1.6)	13.5 (1.8)	11.7 (1.6)	1.8	27.1 (1.9)	29.1 (2.1)	26.9 (2.0)	2.2

Note. Standard errors are shown in parentheses below their respective means.

$F < 1$. The main effect of congruency was also significant, $F(1, 25) = 18.5$, $MS_e = 3{,}652$, $\eta = .43$; incongruent RTs (744 ms) were longer than neutral RTs (714 ms).

Display set size interacted with congruency, $F(2, 50) = 6.4$, $MS_e = 1{,}590$, $\eta = .20$. Contrasts indicated that this interaction existed within the 2-letter and 6-letter conditions. That is, interference was greater in the 2-letter condition (51 ± 14 ms) than in the 6-letter condition (26 ± 21 ms), $F(1, 25) = 5.4$, $MS_e = 3{,}098$, $\eta = .18$, but interference did not differ in the 6-letter and 8-letter (12 ± 16 ms) conditions, $F(1, 25) = 1.3$, $MS_e = 3{,}857$. Cue set size also interacted with congruency, $F(1, 25) = 4.6$, $MS_e = 1{,}221$, $\eta = .16$, but in the opposite direction: There was *less* interference from distractors in the 2-cue condition (21 ± 11 ms) than in the 6-cue condition (38 ± 20 ms).

The same ANOVA was conducted on error percentages. The three-way interaction was not significant, $F < 1$. The main effect of cue set size was significant, $F(1, 25) = 154.4$, $MS_e = 49.7$, $\eta = .86$, indicating that fewer errors were made in the 2-cue condition (10.9%) than in the 6-cue condition (20.8%). The main effect of display set size was also significant, $F(2, 50) = 130.0$, $MS_e = 27.9$, $\eta = .84$. Contrasts indicated that fewer errors were made in the 2-letter condition (9.1%) than in the 6-letter condition (18.1%), $F(1, 25) = 141.0$, $MS_e = 58.6$, $\eta = .85$, and that fewer errors were made in the 6-letter condition than in the 8-letter condition (20.3%), $F(1, 25) = 18.8$, $MS_e = 28.0$, $\eta = .43$. This evidence, consistent with Experiment 3A, demonstrates that increases in both cue set size and display set size each produced a task performance cost; in particular, there was a significant additional cost for the 8-letter condition over the 6-letter condition in the error data that was not reliable in the RTs.

Cue set size and display set size interacted, $F(2, 50) = 68.3$, $MS_e = 22.2$, $\eta = .73$. Contrasts indicated that the effect of the cue set size manipulation (6-cue minus 2-cue condition) was smaller for the 2-letter condition (1.2%) than for the 6-letter condition (13.1%), $F(1, 25) = 67.0$, $MS_e = 55.1$, $\eta = .73$, and that the effect was smaller for the 6-letter condition than for the 8-letter condition (15.4%), $F(1, 25) = 4.8$, $MS_e = 28.3$, $\eta = .16$. The main effect of congruency was also significant, $F(1, 25) = 29.8$, $MS_e = 12.7$, $\eta = .54$; more errors were made in the incongruent condition (16.9%) than in the neutral condition (14.7%).

The interaction of display set size and congruency was not significant, $F < 1$. Although the interaction of cue set size with congruency also was not significant, $F(1, 25) = 3.8$, $MS_e = 4.0$, $p = .06$, $\eta = .13$, the marginal trend indicated that there was less interference from distractors in the 2-cue condition (1.5%) than in the 6-cue condition (3.0%), further suggesting that distractor interference increases with cue set size.

Discussion. In both Experiments 3A and 3B, distractor interference decreased with increasing display set size but increased with increasing cue set size, consistent with Experiments 1 and 2. Experiment 3A demonstrated that the effect of cue set size on distractor processing holds in a situation in which the cues in the 6-cue condition provide useful information for guiding attention to a subset of the possible locations. Experiment 3B confirmed this and also showed that neither the effect of the cue set size manipulation nor the effect of the display set size manipulation was attributable to lateral masking effects, in that the same effects held when the search letters were presented at much greater eccentricity.

Furthermore, we again found evidence that the reduction in distractor interference with increasing display set size is similar regardless of whether the additional letters are irrelevant or relevant. The addition of four irrelevant letters (2-cue, 6-letter vs. 2-cue, 2-letter condition) reduced distractor interference 20 ms (Experiment 3A) and 27 ms (Experiment 3B); the addition of four relevant letters (6-cue, 6-letter vs. 6-cue, 2-letter condition) reduced distractor interference 27 ms (Experiment 3A) and 23 ms (Experiment 3B).

General Discussion

In all of our experiments, set size was manipulated in two ways—by varying the number of relevant, cued locations, and by varying the number of letters displayed. There were two critical findings. First, regardless of the method used to manipulate set size, increasing the set size increased RT, which presumably reflects an increase in the task difficulty. In contrast, these set size manipulations produced opposite effects on the extent to which the distractor was processed, with increases in display set size leading to reduced distractor interference, and increases in cue set size leading to increased distractor interference. Second, adding letters in cued relevant locations increased task difficulty more than did adding letters in irrelevant locations. However, the reduction in interference with increasing display set size was the same regardless of whether the additional displayed letters were presented in relevant (cued) or irrelevant locations.

An Aside on Power

The finding that increases in the display set size produced the same reduction in interference regardless of whether the additional letters were relevant or irrelevant relies on a null effect, specifically the absence of a reliable three-way interaction of cue set size, display set size, and congruency. Despite this being a very consistent pattern over the five experiments reported here, to ensure that we had enough power to support this element of our conclusion, we carried out an additional ANOVA on the combined RTs from all of our experiments. (Note that because Experiments 1, 2A, and 2B did not have an 8-letter condition, the 8-letter condition was not included from Experiments 3A and 3B.) Because the findings were similar in all of the experiments, it is not surprising that the combined analysis produced the same pattern of results and conclusions: There were significant effects (all ps $< .001$) of cue set size, $F(1, 129) = 262.5$, $MS_e = 6767$, display set size, $F(1, 129) = 259.0$, $MS_e = 5718$, cue set size by display set size, $F(1, 129) = 116.0$, $MS_e = 3{,}634$, congruency, $F(1, 129) = 131.7$, $MS_e = 1{,}990$, cue set size by congruency, $F(1, 129) = 31.7$, $MS_e = 629$, and display set size by congruency, $F(1, 129) = 37.1$, $MS_e = 889$. Critically, the three-way interaction of cue set size, display set size, and congruency was still not significant, with an $F < 1$. The lack of a three-way interaction with this greatly increased sample size heightens our confidence that the consistently observed reduction in interference with the addition of display letters is the same regardless of whether the additional letters are relevant or irrelevant. This pattern is inconsistent with Lavie and Tsal's (1994; Lavie, 1995) view that relevance is a crucial determinant of interference. Figure 3 provides a summary of this analysis across all three experiments using interference scores and within-subject

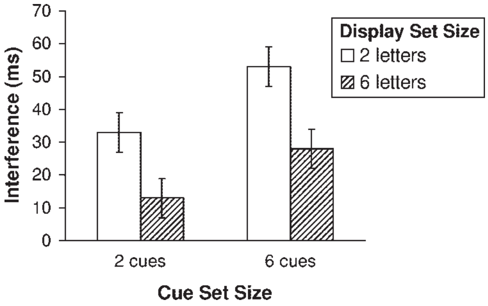

Figure 3. Experiments 1, 2, and 3: Interference as a function of cue set size and display set size with 95% within-subject confidence intervals as recommended by Loftus and Masson (1994). Interference is defined as uncued RT minus cued RT. Note that to permit inclusion of data from all three experiments, the condition with a display set size of 8 in Experiment 3 is not included.

confidence intervals, as recommended by Loftus and Masson (1994).

The fundamental prediction of the load account (Lavie & Tsal, 1994) is that increases in relevant perceptual load lead to decreases in distractor processing. This view is thus unable to account for our first finding of increased interference with increases in the cue set size. Furthermore, the load hypothesis is unable to account for our second finding that, regardless of whether load was increased by adding task-relevant letters or by adding task-irrelevant letters, and despite the fact that the addition of task-relevant letters had a larger impact on perceptual load than did the addition of task-irrelevant letters, the same reduction in distractor interference was observed.

The Dilution Account

With the load account unable to explain our results, we have offered an alternative dilution account. In our explanation, visual search is held to be a two-stage process, similar to that proposed by Neisser (1967) and Hoffman (1979; see also Hoffman et al., 1983). In the first stage, all displayed items are processed in parallel, with each item compared to the target representations stored in memory. The location containing the item most similar to one of the target representations is selected for focused attention in the second stage. In the second stage, capacity is limited and attention is focused on the stimulus at the selected location. Because attention is now focused on the single item most likely to be the target, all of the search items at the other locations—plus the designated distractor—are irrelevant information. The relevant perceptual load for the second stage is the processing of the one item at the most probable location. The irrelevant items (the other search letters and the distractor) are then processed, as Lavie and Tsal (1994) proposed, to the extent that there are sufficient spare resources.

Under the dilution view, increasing the display set size affects the second, focused attention, stage of visual search. Note that the relevant perceptual load is the same (one item) for this second stage regardless of the number of other items presented, and regardless of whether those items were or were not relevant during the first stage. As the display set size is increased, dilution during the focused attention stage increases, which in turn reduces distractor processing and distractor interference. Or, put differently, crosstalk increases, which in turn degrades the distractor representation and reduces distractor interference. Either way, the dilution account explains the finding that increasing the display set size with relevant letters produces the same reduction in distractor interference as does increasing the display set size with irrelevant letters.

To account for the cue set size effect on distractor interference, we have proposed that increases in the cue set size increase uncertainty (i.e., decision noise) regarding the target location during the first parallel processing stage. This increased uncertainty slows the determination of the most probable target location, which increases the length of time spent in this parallel processing stage. The increased time spent in this parallel processing stage should increase distractor processing and distractor interference. In summary, an increase in the cue set size increases decision noise, which increases the time spent in the first, parallel processing, stage, which should increase distractor processing and distractor interference. A closely linked second interpretation of the cue set size manipulation is possible: With increased uncertainty in the target location, attentional breadth may increase. An alternative interpretation, then, is that cue set size leads to increased attentional breadth that would be expected to lead to increased distractor processing.

Dilution versus Load

It should be emphasized that the load account and the dilution account are “sibling” theories in that both attempt to explain selective attention via limited-capacity resource models. However, there are three principle differences between these two accounts. First, the dilution account incorporates two perceptual processing stages—an initial parallel processing stage followed by a focused attention stage, whereas the load account seems to be underspecified with regard to this issue. That is, there is no explicit indication that proponents of the load account conceive of two perceptual processing stages, certainly not in the way that we do and others have (Neisser, 1967; Hoffman, 1979; Hoffman et al. 1983). In fact, we interpret the load account as an alternative to two-stage explanations. Second, the dilution account incorporates the idea that an increase in decision noise (see Palmer, 1994, 1995; Palmer et al., 1993) slows determination of the most probable target location and increases time spent in the initial parallel processing stage. Third, the dilution account incorporates the idea that dilution or cross-talk during the second parallel processing stage among nontarget items influences the extent to which distractors are processed. Although there may be multiple ways in which the load account could be modified to accommodate our findings, the only way clear to us would be to incorporate all three of these differences.

Converging Evidence for the Dilution Account

Our research converges with the findings and conclusions of recent research conducted on load and dilution (Benoni & Tsal, 2010; Tsal & Benoni, in press). Similar to us, these researchers were concerned that the previous research examining the impact of load on selective attention had inappropriately operationalized load with a set size manipulation, and they suggested that use of this operational definition meant that load was confounded with dilution. That is, as set size increases, both perceptual load and dilution presumably increase. Their solution to disentangle this confound was to use a third condition, a "low load, high dilution" condition.

For example, in Experiment 1 of Benoni and Tsal (2010), the task was to identify a target letter of a specific color (e.g., green) presented either in isolation or with three nontarget letters near fixation. As with previous load studies and our study, selective attention was assessed by the extent to which performance was affected by a congruent versus incongruent distractor letter presented in a peripheral position (left or right of the central target and nontarget letters) and in a unique color (white). There were three experimental conditions: (1) a "low load and low dilution" condition in which the green target letter was presented in isolation (except for the peripheral distractor), (2) a "high load and high dilution" condition in which the green target letter was presented with three nontarget letters of the same color, and (3) a "low load and high dilution" condition in which the green target letter was presented with three nontarget letters of a different color (e.g., red). The first two conditions are similar to those used in many load studies and confound load with dilution. In the last condition, because the participants knew that the target was green, the three red nontarget letters had little impact on performance (confirmed via a comparison of overall RTs), and thus produced a low load processing mode. However, this last condition was considered high dilution because the three nontarget letters were still expected to compete with the distractor letter for lexical representation.

To assess the load effect, Benoni and Tsal (2010) compared the "high load and high dilution" condition with the "low load and high dilution" condition, Distractor interference did not differ between these conditions; in fact, distractor interference was not evident in either condition, suggesting that load had no impact on the extent to which the distractor was processed. To assess the dilution effect, they compared the "low load and low dilution" condition with the 'low load and high dilution" condition. Distractor interference was evident in the "low load and low dilution" condition but, as just discussed, it was not evident in the "low load and high dilution" condition. Therefore, the increase in dilution resulted in the elimination of distractor interference. In summary, their results consistently supported the idea that perceptual load is not the primary determinant of the extent to which a distractor is processed; rather, the extent to which a distractor is processed is determined by dilution caused by the presence of other nontarget letters.

The results of our study are consistent with theirs. Our study clearly supports the concept of dilution—as display set size increased, dilution should increase and, as expected, distractor interference decreased. Also consistent with their findings, we failed to support the primary prediction of the load account (Lavie & Tsal, 1994)—that increasing the relevant perceptual load should lead to decreased distractor processing. In fact, we found consistent evidence for the opposite—as cue set size increased, there was *increased* distractor interference. Consistent with our results and clearly inconsistent with the load account, Tsal and Benoni (in press) also found a "reversed load" effect in 2 of their 4 experiments.

Our conceptualization of dilution differs slightly from Tsal and Benoni (in press) and Benoni and Tsal (2010) in two ways. First, we emphasize a two-stage account of visual search in which dilution primarily impacts distractor processing during the second stage of focused attention. In contrast, while not explicitly framing their position as a two-stage account, they suggest that dilution originates at an early stage of visual processing. We agree that dilution could occur during the first stage of parallel visual processing, but our results—specifically, our finding that increasing the display set size with relevant letters produces the same reduction in distractor interference as does increasing the display set size with irrelevant letters—suggest that the impact of dilution on distractor processing is largely occurring during a second focused attention stage.

A second difference in these two dilution accounts is that Tsal and Benoni (in press) suggest that increasing load leads to longer processing time and thus greater opportunity for distractor interference. We make a similar suggestion but the findings from our cue set size manipulation led us to conclude that the increased opportunity for distractor interference was largely occurring during the first stage of parallel visual processing. Specifically, we suggest that increasing the cue set size increases uncertainty regarding the target location during the first parallel processing stage. This slows the determination of the most probable target location and thereby increases the length of time spent in this parallel processing stage, leading to greater distractor interference. To understand why Tsal and Benoni's (in press) claim of a direct positive relation between load and distractor interference is not sufficient, we can examine our cue set size manipulation for each display set size: (1) when the display set size was 2 letters, increasing the number of cued locations from 2 to 6 produced a small increase in load; (2) however, when the display set size was 6 letters, increasing the number of cued locations from 2 to 6 produced a large increase in load. If, as Tsal and Benoni suggest, load produces a direct increase in greater interference, then the increase in distractor interference should have been greater for the second comparison with a 6-letter display set size and the larger increase in load. However, our results indicate that, regardless of the increase in load via the cue set size manipulation, the increase in distractor interference did not differ (see Figure 3).

In summary, except for these two differences in which we emphasize the need for a two-stage account of visual search, our results and those of Tsal and Benoni (in press) and Benoni and Tsal (2010) provide converging evidence against the load account of Lavie and Tsal (1994), and support the notion that dilution, not load, is the primary determinant of distractor processing.

Endogenous Cue and Load Finding

Using a search procedure similar to that used in the Lavie and Cox (1997) experiments and in the present experiments, Johnson, McGrath, and McNeil (2002) examined the influence of a valid central arrow cue on selective attention. The target letter (X or N) appeared in one of six locations. In the low load condition, the letter O was placed at each of the five remaining locations; in the high load condition, a heterogeneous set of letters (K, M, Z, W, and H) was distributed in the five remaining locations. In a valid-cue condition, a valid central arrow cue identifying the target location was presented 200 ms before the letter display; in a no-cue condition, no cue was presented. A distractor letter always appeared in the periphery. In the no-cue condition, there was significantly more distractor interference for the low load condition relative to the high load condition, consistent with the Lavie and

Cox finding. In the valid-cue condition, distractor interference did not differ for the low and high load conditions.

Because both the cue and the load affected distractor interference, Johnson et al. (2002) concluded that perceptual load, despite being an important factor, is not the only factor that determines attentional selectivity. Our results advance the theory a further step. Although we agree with Johnson et al. that perceptual load still plays a role in attentional selectivity, our results suggest that the effect of perceptual load on distractor interference is not mediated by the level of spare capacity, contrary to the Lavie and Tsal (1994) proposal. Instead, we argue that perceptual load changes the number of elements among which processing resources must be shared or over which dilution occurs during a second stage of focused target processing. Thus, we suggest that increasing perceptual load produces increased dilution of resources, and that it is this dilution that leads to reduced distractor processing and hence to reduced interference.

Load Increasing versus Stimulus Degrading

Lavie and de Fockert (2003) argued that increases in task difficulty do not always reflect increases in perceptual load. They suggested that task difficulty can also be increased by degrading the relevant stimulus. By arguing that target degradation does not produce an increase in perceptual load, they hypothesized that this degradation would have no effect on the extent to which an irrelevant distractor is processed. Using a search procedure similar to that of Lavie and Cox (1997), they varied perceptual load by varying set size. In the degraded condition, the target stimulus was degraded by reducing its size and intensity, by reducing its duration and masking it, or by increasing its eccentricity. Replicating Lavie and Cox, Lavie and de Fockert found that increasing the set size reduced distractor interference. In contrast, degrading the target stimulus led to increased distractor interference. They took this as support for their hypothesis that stimulus degradation does not truly constitute a manipulation of perceptual load, and that increasing the task difficulty without increasing the perceptual load is not sufficient to reduce distractor interference.

Our experiments show that increasing the relevant perceptual load, rather than degrading the target stimulus, can also produce an increase in distractor interference. This is most clear in a comparison of the 2-cue, 6-letter condition with the 6-cue, 6-letter condition. The letter display is identical in these two conditions, suggesting that the target stimulus quality does not differ in these conditions. However, the number of relevant locations and the number of relevant letters is increased by four in the latter condition. This is a direct manipulation of relevant perceptual load, with the latter condition containing six relevant letters and the former two relevant letters. In fact, this manipulation of cue set size without changing the display set size would seem to be an improved manipulation of relevant perceptual load compared to Lavie and Cox's (1997) and Lavie and de Fockert's (2003) set size manipulations, which confound cue set size with display set size. Therefore, we have evidence that an increase in relevant perceptual load that is not confounded with an increase in number of displayed items produces increased distractor interference. This pattern is clearly inconsistent with the load account.

Finally, note that the finding of Lavie and de Fockert (2003) is consistent with our dilution account (but for a contrary result, see Yi, Woodman, Widders, Marois, & Chun, 2004). Because target degradation necessitates greater perceptual processing, degradation might be expected to lead to greater time spent during the initial stage of parallel processing. The dilution account would suggest that the greater time spent during this parallel processing stage would lead to greater distractor processing and greater distractor interference, which is exactly what Lavie and de Fockert found.

Central versus Peripheral Distractor

We deviated from the Lavie and Cox (1997) procedure by placing the irrelevant distractor in the center of the display rather than in the periphery. The first reason for making this change was to increase the magnitude of distractor interference, moving it as far off floor as possible. Beck and Lavie (2005) used this procedure with the result that the magnitude of distractor interference increased for central distractors relative to peripheral distractors (see Wilson, MacLeod, & Muroi, 2008, for the same result but only under certain conditions). With the distractor in the periphery, distractor processing is typically eliminated (i.e., reduced to floor) in high perceptual load conditions (e.g., Lavie & Cox, 1997). Although floor effects may be acceptable when making a simple comparison between a low load and a high load condition, floor effects create significant interpretation problems in comparisons of different manipulations of load. Our Experiment 2 highlights such problems that can arise in interpretation if some of the effects are close to floor.

The second reason for moving the irrelevant distractor to fixation was to ensure that the distractor was the same distance from the target on all trials, which is not the case when the distractor is presented at a peripheral location. Although it is clear that distractor processing is likely greater when the target is close to the distractor (e.g., Miller, 1991), of more concern is that other research in our laboratory suggests that this effect of distractor distance might interact with set size.

Finally, in our close replication of the Lavie and Cox (1997) procedure using a peripheral distractor and a modified version using a central distractor (Wilson et al., 2008), we found that this change in the distractor location did not affect overall RT, and that it also did not reliably influence the load effect; in both cases, as set size increased, distractor interference decreased. However, it is important to note that the possibility remains that manipulations of load could have qualitatively different effects on distractor processing for distractors presented in central locations versus those presented in peripheral locations.

Hybrid Load Account

Lavie, Hirst, de Fockert, and Viding (2004; see also Lavie, 2000) have proposed a modification to the load account—a hybrid account in which there are two selection components. First, there is the "passive" perceptual selection mechanism which is identical to the selection-mediated-by-load idea of the original load account. That is, under high perceptual load conditions, processing capacity is exhausted, leaving insufficient capacity for the processing of distractors. Second, there is an additional "active" selective attention component—the active control system—which is responsible, in low perceptual load situations, for maintaining task priorities and for preventing irrelevant information from interfering with current processing goals. This "active control" mechanism is thought to be used in low perceptual load situations because it is in these situations that the passive process will fail to prevent distractor processing. Critically, the active control process is proposed to rely on higher cognitive control processes, specifically working memory. Therefore, in contrast to the effects of perceptual load, an increase in working memory load is theorized to reduce the capacity available for "active control" and consequently to reduce its ability to prevent distractors from affecting behavior. In sum, increases in the load of higher cognitive functions are expected to increase distractor processing and distractor interference (for a similar idea regarding the role of working memory in controlling visual attention, see Kane, Bleckley, Conway, & Engle, 2001).

To test the hybrid hypothesis, Lavie et al. (2004, Experiment 1) examined the effect of a working memory load manipulation on selective attention. On each trial, participants were first presented with a memory set of 1 or 6 digits, then performed a search task while ignoring an irrelevant distractor, and finally responded to a memory probe. Distractor interference in the search task was greater when memory load was high than when it was low. Consistent with the hybrid load model, the increase in working memory load was suggested to reduce available working memory and consequently to reduce the efficiency of the active selective attention mechanism (see also Lavie & de Fockert, 2005).

Further evidence that an increase in working memory load produces increased distractor interference comes from neuroimaging studies (de Fockert, Rees, Frith, & Lavie, 2001; Lavie & de Fockert, 2006; Rees, Frith, & Lavie, 1997; but for a contrary result, see Yi et al., 2004). For example, in the de Fockert et al. study, participants held in working memory either an easy series of digits (always in the same order) or a hard series of digits (with order varying from trial to trial), then had to classify famous written names as pop stars or politicians while ignoring faces that were either congruent, incongruent, or neutral with the required response. The higher memory load of the hard series led to greater interference from the irrelevant faces, more prefrontal activation characteristic of the use of working memory, and more visual cortex activation consistent with greater face processing.

Hybrid Load Account of Our Data

It has been suggested to us that the Lavie et al. (2004) hybrid load hypothesis might be able to account for the current set of experiments if we were to conceive of our display set size manipulation as a perceptual load manipulation and our cue manipulation as a working memory manipulation. We agree that if our factors were interpreted in this way, then the hybrid load model would accurately predict that an increase in display set size decreases distractor interference, whereas an increase in cue set size increases distractor interference. However, there are several reasons why such an interpretation is probably incorrect.

We note first that such an interpretation of cue set size would be inconsistent with the perceptual load definition used originally by Lavie and Tsal (1994), and still used by Lavie (2005)—increases in perceptual load can be achieved either by increasing the number of items requiring perceptual processing or by increasing the processing operations required for the same number of items. To understand the latter aspect of this definition, consider Experiment 2A of Lavie (1995) in which perceptual load was manipulated by making a cue more or less difficult to interpret in a go-no go task. Lavie (1995) claimed that this cue manipulation affected perceptual load, in that, in the low load condition (using a feature cue) the participant had to process one dimension of the go-no go cue, whereas in the high load condition (using a conjunction cue) the participant had to process two dimensions of the cue. In the Lavie (2005) review, this conjunction cue versus feature cue manipulation is also described as a perceptual load manipulation—"Perceptual load is manipulated by increasing perceptual processing requirements for the same displays" (p. 76). This definition of perceptual load has also been used in other studies that have kept the stimulus displays constant and have manipulated the processing requirements (e.g., Rees et al., 1997; 2001).

We have stayed true to this definition of perceptual load in the current study. Consider a comparison of our 2-cue, 6-letter versus 6-cue, 6-letter conditions—a cue set size manipulation. These two conditions consist of the same 6-letter displays but, via precues, we have manipulated the perceptual processing requirements for these letter displays. In fact, we see this as a better manipulation of perceptual load than that used by Lavie and Cox (1997; also Lavie & de Fockert, 2003) because their set size manipulations confound cue set size with display set size. It is therefore clear that defining our cue set size manipulation not as a perceptual load manipulation but as a working memory manipulation would be inconsistent with the definitions of perceptual load used by Lavie and her colleagues.

Second, it is certainly the case that our cue set size manipulation significantly affects perceptual load. Again, consider a comparison of the 2-cue, 6-letter condition with the 6-cue, 6-letter condition—a cue set size manipulation. The latter case clearly requires perceptual processing of four more letters. In fact, with three times the number of letters presented in the 6-letter condition, the definition of perceptual load would imply that perceptual load has tripled.

Third, we note that reinterpreting cue set size as a working memory manipulation is post hoc, and most researchers who we have consulted have actually suggested the opposite—that is, at least for Experiments 1 and 2 using a maximum of 6 letters, the 2-cue conditions may require more selective attention and may be more demanding on working memory than the 6-cue conditions. Specifically, the 6-cue condition might not be demanding on working memory resources in that selection might not be necessary and one might be able to passively attend to all locations, whereas the 2-cue condition might require more resources to select the relevant locations and to filter out the irrelevant locations.

Fourth, care must be taken to avoid a confirmatory bias such that we designate any load manipulation found to decrease distractor interference as a perceptual load manipulation, and any load manipulation found to increase distractor interference as a cognitive control manipulation. This would result simply in circularity. For example, consider the following inconsistency in the interpretation of a target degradation manipulation. As described earlier, Lavie and de Fockert (2003) argued that perceptual degradation of a target stimulus was not a perceptual load manipulation and found, in support of this interpretation, that target degradation led to increased distractor interference. However, Yi et al. (2004) also degraded target stimuli (by adding "salt and pepper" noise to face stimuli) and found, in contrast to Lavie and de Fockert, that this led to increased distractor interference. Again in contrast to Lavie and de Fockert, Yi et al. interpreted target degradation as a perceptual load manipulation. It is clear that there is some inconsistency in the interpretation of these target degradation manipulations.

Finally, we note that the interpretation of the effects of our cue set size manipulation and other load manipulations remains open to debate (for a similar claim, see Tsal & Benoni, in press). For example, there may even be reason to question whether the perceptual load manipulation used by Lavie and Cox (1997) truly affects perceptual processing. Palmer (1994, 1995; Palmer, Ames, & Lindsey, 1993) has argued for unlimited capacity, parallel perceptual processing, such that the addition of similar nontargets does not actually affect perceptual processing. Instead, the addition of nontargets is seen as adding decision noise to a postperceptual stage, which reduces ability to identify the target. Extending this view, the reason for decreased task performance with increased set size may not be attributable to an increase in perceptual load but instead to an increase in the difficulty of a postperceptual decision-making process.

In summary, interpreting the cognitive and neural effects of these load manipulations is not entirely straightforward. More often than not, load manipulations likely affect both perceptual and cognitive control systems. In fact, any task that we as researchers ask our participants to perform undoubtedly requires some cognitive control; otherwise participants could not selectively attend to task-relevant stimuli, or generate task-appropriate responses. Finally, our interpretation of the cue set size manipulation is that, although it does require active control over attentional allocation, the consequences of this manipulation have a much larger impact on perceptual load than on cognitive control load.

Conclusion

Because of parallels observed between the addition of relevant items (as in the search procedures of Lavie & Cox, 1997) and the addition of irrelevant items (as in the Stroop dilution procedures of Kahneman & Chajczyk, 1983) in a visual search task, we formulated a dilution account. This account provides a viable alternative to Lavie and Tsal's (1994) load account, which they proposed as an explanation of the finding of decreased distractor interference with increases in set size. We conclude that the reduced interference associated with increases in set size (e.g., Lavie & Cox, 1997) is not caused by an increase in relevant perceptual load and the resultant reduced spare capacity. Rather, the reduction in distractor interference is caused by a dilution of distractor processing when more nontarget items are present.

In summary, we see the dilution account as an improvement over the original load account and at least as a viable alternative to the hybrid load account (Lavie et al., 2004). It remains possible, though, that the load account, with several modifications, could incorporate the concept of dilution, in essence merging the two accounts. Although the extant load account cannot readily explain our findings, given its success in accounting for the results of numerous previous selective attention studies, we do not believe that it should be abandoned based solely on our study. Yet we are encouraged that both our work and that of Benoni and Tsal (2010; Tsal & Benoni, in press) converge on the conclusion that dilution, not load, is the primary determinant of distractor processing.

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