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Does Crowding Obscure the Presence of Attentional Guidance in Contextual Cueing?

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in Contextual Cueing?

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Abstract

The contextual cueing effect was initially thought to be the product of memory guiding attention to the target location. However, the steep search slopes obtained in contextual cueing indicate an absence of attentional guidance. We hypothesized that crowding could be obscuring the presence of attentional guidance and investigated this possibility in 2 experiments. Crowding was manipulated by varying the density of items in the local target region in a contextual cueing task. We observed a significant reduction in search slopes between the novel and repeated conditions when crowding was reduced. Enhancing crowding eliminated the contextual cueing effect. These findings suggest that increased crowding at larger set sizes attenuates the memory-based attentional guidance in contextual cueing thereby producing steep search slopes.

Introduction

The visual world abounds with a vast plethora of stimuli for the perceiver. At any given moment, an overwhelming quantity of sensory information inundates the visual system and competes for its limited processing resources. This input must be rapidly prioritized selecting only behaviorally relevant information for extensive processing while ignoring the mass of irrelevant information. In the case of visual search, this attentional selection allows us to efficiently locate some particular object, or target, within a scene. There are a variety of factors that the visual system may take advantage of to improve search efficiency. In particular, familiarity with the spatial context of the scene is known to facilitate visual search performance. The mechanism underlying this intriguing memory-attention interaction, termed *contextual cueing*, is the subject of ongoing debate.

In their seminal paper, Chun & Jiang (1998) observed a reduction in mean response time (RT) when search displays were repeated as compared to novel displays. While these behavioral findings are provocative, the cognitive processes involved in this facilitation are somewhat opaque. It is clear that contextual cueing reflects learning of the spatial layout of the repeated displays, as their repetition is all that distinguishes them from the novel displays. The question is how the memory for those displays is ultimately producing lower mean RTs in the repeated condition. As has been noted previously (Palmer, Ames, & Lindsey, 1993; Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002), a reduction in RT in visual search merely indicates that some stage of processing has been facilitated, not which particular stage or stages. For example, facilitation may occur during early perceptual processing of the display, during the search process itself, or at decision/response stages.

Facilitation of search proper has been the favored explanation for the contextual cueing effect with Chun & Jiang (1998) initially hypothesizing that informative contexts become associated with target locations. Upon implicit recognition of the repeated context, spatial attention is then guided to the target location increasing the efficiency of search and consequently decreasing overall reaction time. When the number of items in the display (set size) is manipulated across trials, the slope derived from the RT x set size function is typically taken as a measure of the efficiency of the search process. Shallower slopes indicate more efficient search and the presence of attentional guidance. In contextual cueing experiments, the slope of the repeated condition can be compared to the slope of the novel condition, providing a direct measure of the change in search efficiency between the two conditions. Chun & Jiang (1998 – Exp. 4) observed a reduction in search slope from the novel to the repeated condition (~40ms/item and ~30ms/item respectively) supporting their attentional guidance account.

Recently, Kunar and colleagues (2007) have advocated a response facilitation account of the contextual cueing effect. They note that while Chun & Jiang (1998) did obtain a significant decrease in search slope, it remained relatively high (~30ms/item) in the repeated condition. Furthermore, the authors failed to observe a significant reduction in search slope in a number of their own studies (Kunar, Flusberg, Horowitz, & Wolfe, 2007). A small contextual cueing effect was still obtained even under conditions where search efficiency was already perfect (a set size of one, or with simple feature search), thus leaving no room for additional guidance. When interference was introduced at the response selection stage, the effect disappeared suggesting that it is at least partially the product of speeded responses for familiar contexts. Taken together with the failure to observe significantly decreased search slopes, the authors concluded that these findings support only a modest role for attentional guidance in contextual cueing, with response facilitation constituting the primary driver of the effect. They postulate the presence of a ‘response threshold’ which requires a certain amount of information regarding the to-be-made response in order to be crossed. This threshold is lowered by the recognition of the repeated display allowing it to be crossed sooner resulting in the contextual cueing effect. Thus, while the target may not necessarily be located faster in repeated displays, it can be responded to faster once it is located. Findings from eye tracking and ERP research support roles for both search and response selection components in producing the contextual cueing effect. Both decreased numbers of fixations for repeated vs. novel trials (Peterson & Kramer, 2001; Tseng & Li, 2004; Manginelli & Pollmann, 2009) and enhanced ERP components reflecting the allocation of spatial attention for repeated trials (Schankin & Schubo, 2009; Johnson, Woodman, Braun, & Luck, 2007) have been observed in contextual cueing experiments. This raises the question of why behavioral evidence for an increase in search efficiency in contextual cueing is generally lacking despite significant support from numerous psychophysiological studies? We examined a possible answer to this question in the present study.

Established sources of attentional guidance like color, motion, orientation, etc., are derived from characteristics of the stimuli in the scene or display (Wolfe et al, 1989; Wolfe & Horowitz, 2005). We will refer to this type of guidance as *feature-based*. In contextual cueing however, memory, not stimulus features, serves as the candidate source of guidance. This has potentially significant consequences for applying traditional criteria, for example search slope, in evaluating the contextual cueing effect. Attentional guidance derived from memory would be subject to unique limitations that could change depending on the amount of information involved in the process. Specifically, we hypothesized that changing perceptual characteristics of the display moderate *memory-based* attentional guidance as set size increases. The diminishing efficacy of the guidance, rather than its absence, could be producing the steep search slopes observed in contextual cueing experiments.

The influence of sensory/perceptual phenomena like eccentricity and lateral masking on visual search has been investigated previously and found to have minimal impact on set size effects (Palmer, 1994; Palmer, Ames, & Lindsey, 1993; Poder, 2004). However, the unique nature of the candidate guidance in contextual cueing gives them new potential. Effects of this nature and in particular, a phenomenon known as visual crowding (Levi, 2008; Pelli, Palomares, & Majaj, 2004) could significantly impair the efficacy of memory-based guidance at larger set sizes.

Visual crowding is a limitation of visual processing concerning the identification of objects in the peripheral visual field. In a general sense, objects in the periphery that would be identifiable in isolation become considerably more difficult to recognize when they appear with other items (flankers) in close proximity. The spatial extent of crowding – the target-flanker distance beyond which recognition is no longer impaired – is known to be a function of the target's viewing eccentricity. This critical spacing is described by *Bouma's Law* (Bouma, 1970) as being roughly the 0.4 times the eccentricity (Pelli, Palomar, & Majaj, 2004). The prevailing theory of crowding is a two-stage model where information in the periphery is processed via integration fields that increase in size with eccentricity (Levi, 2008; Pelli, Palomares, & Majaj, 2004). The first stage involves detection of simple features with the second stage integrating those features within their respective integration fields. Crowding occurs because features of the target and flankers are detected independently but are inappropriately integrated into a single jumbled percept if they fall within the same integration field.

This phenomenon is especially relevant to contextual cueing given the assertion of Chun & Jiang's (1998) associative-learning hypothesis that attention is guided to the local target region on repeated trials. If this region is largely empty save for the target – more likely with smaller set sizes – the target may be recognized in the periphery, allowing attention to be guided directly to it. However, if the local target region is cluttered with distractors – more likely with larger set sizes – then crowding will impair peripheral recognition of the target. The consequences of this impairment are hard to predict, but it could potentially limit guidance to constraining search to the local target region, or even eliminate it altogether with search proceeding in normal, inefficient fashion. Because the target is less likely to be alone in its integration field as set size increases, crowding represents a potential culprit behind the steep search slopes observed in contextual cueing. That the impact of crowding is highly dependent on target-flanker similarity, especially in shape, size, and orientation (Kooi, Toet, Tripathy, & Levi, 1994; Andriessen & Bouma, 1976; Levi, Hariharan, & Klein, 2002), and is known to occur in letter recognition (Bouma, 1970; Flom, Heath, & Takahashi, 1963; Toet & Levi, 1992) makes it even more of a concern with the very similar target ‘T’s and distractor ‘L’s typically used in contextual cueing displays.

In two experiments, we investigated the influence of crowding on contextual cueing by varying the density of items in the local target region. In Experiment 1A, we conducted a contextual cueing experiment utilizing displays modified to eliminate crowding in half of the trials (Uncrowded condition). These displays were constructed such that no distractors could appear within the critical distance – as defined by *Bouma’s Law* – of the target. The displays on the other half of trials (Normal condition) were typical contextual cueing displays. Experiment 1B utilized the same Uncrowded condition as Experiment 1A, but paired with a Crowded condition this time. Crowding of the target was enhanced by increasing the likelihood that distractors would appear within the local target region. The data from the two Uncrowded conditions were collapsed to increase experimental power and due to the high degree of similarity between the two experiments, they will be presented together with significant differences noted.

We expected the Normal condition to follow previous findings with a significant contextual cueing effect largely supported by intercept, rather than slope differences, between the novel and repeated displays. However, if crowding is diminishing the efficacy of memory-based guidance, two related predictions can be made for the Uncrowded and Crowded conditions. First, eliminating crowding should produce results characteristic of attentional guidance in the Uncrowded condition: a significant reduction in search slope from the novel to the repeated displays. Second, enhancing crowding should attenuate the guidance, potentially even eliminating the contextual cueing effect altogether in the Crowded condition resulting in comparable slopes and intercepts for both novel and repeated displays.

Method

Participants

We selected sixty-four and sixty-one participants with normal or corrected-to-normal vision from the USF undergraduate population for experiments 1A and 1B respectively. The proposed analyses involve considerable dissection of each participant's data and a lot of variability is expected at the level of individual RT means. For these reasons, the sample size used in this study was larger than those typically observed in the literature. Participants received credit toward their research requirement for their psychology classes.

Apparatus and Stimuli

Stimuli were presented on a 20-inch Apple *i*Mac color monitor running an experimental program created with RealBasic. Viewing distance was unrestrained at approximately 60cm. The stimuli and displays used in this experiment closely followed those used in Chun and Jiang's (1998) original experiments including minor modifications in line with the prevailing methods within the literature and those necessary for the crowding manipulations. See Figure 1 for example displays. Stimuli of 1.9 degrees in visual angle (height and width) were presented within an invisible 8 x 8 grid on a display measuring approximately 40 x 32 degrees in visual angle. Stimuli were composed of two white lines of equal length with the background set to a light gray. The distractor stimuli consisted of 'L' shapes oriented randomly at 0, 90, 180, or 270 degrees. There was a small offset at the junction of the lines forming the 'L' making it slightly less discriminable from the target, thus making the task more difficult. The target stimulus was a sideways

‘T’ shape with the base oriented either to the right or the left. Each item was jittered by approximately .5 degrees visual angle within its cell to prevent colinearities with the other items in the display. Feedback in the form of a low-pitched tone was given for incorrect responses.

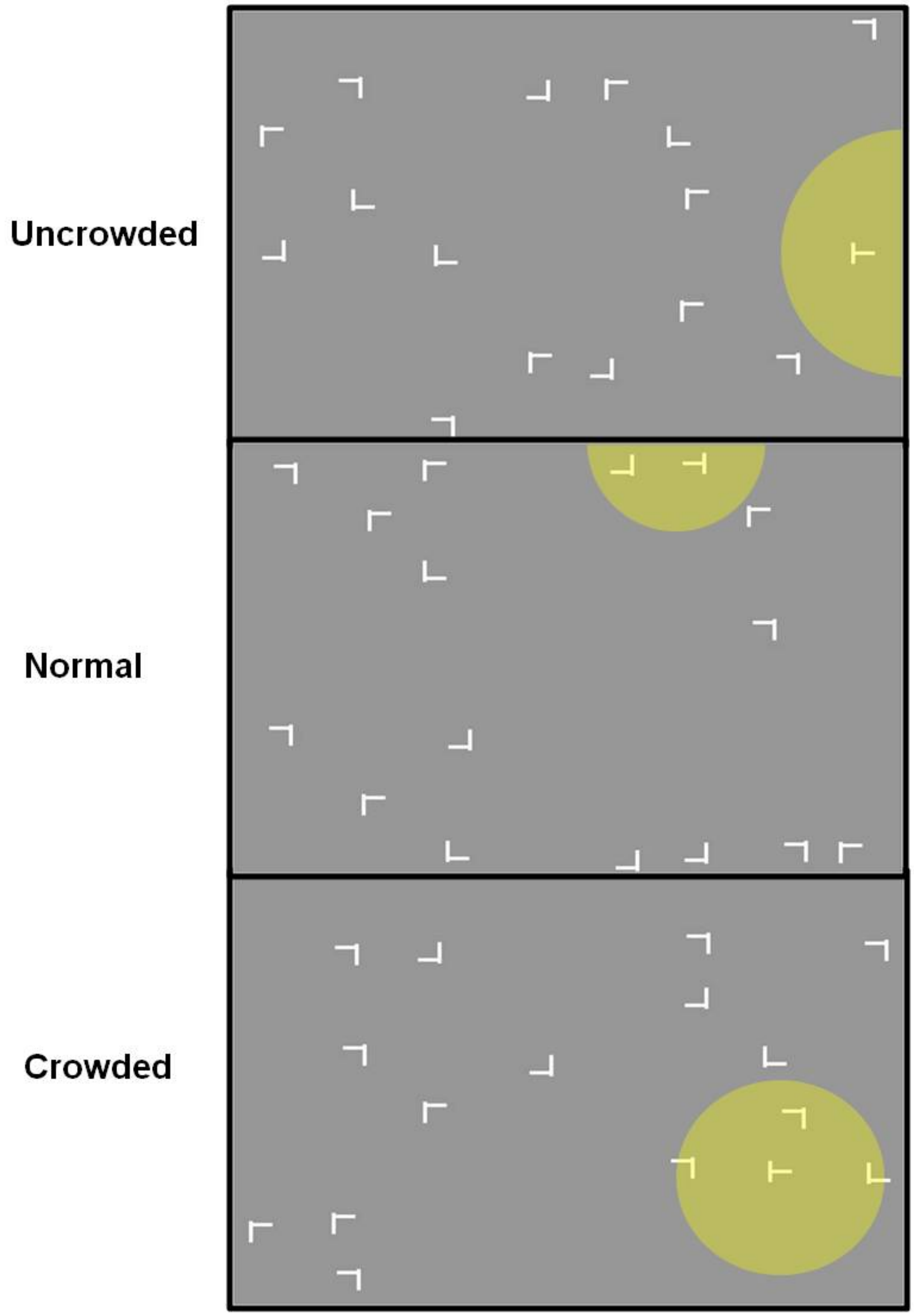

Figure 1. Example Visual Search Displays Used in Experiments 1A and 1B

Each display contained a number of items (determined by the set size for that display) at any of the 64 possible locations with the exception that targets did not appear within the 4 center locations. A constraint ensured that the same number of items appeared in each quadrant of the display. The location and identities of the distractors as well as the target location were held constant throughout the course of the experiment for the repeated displays. The target identity however (pointing right or left), varied randomly (including on repeated displays) in order to prevent the formation of context-response associations. Thus, each repeated display was presented a total of 24 times. The location and identity of the distractors on novel trials varied randomly throughout the experiment. A target was present on every trial. In order to avoid location probability effects, 24 of the 60 possible target locations were randomly selected for each participant, split evenly between repeated and novel trials.

Critically, displays in the Uncrowded condition of Experiments 1A and 1B were modified to control for crowding in the local target region. The consequences of these manipulations can be observed in Figure 1 where the local target region is highlighted in each display. This was accomplished by ensuring that no distractors occurred closer to the target than 40% of the target eccentricity. That is, the target was alone in within its local region as defined by Bouma's Law (Bouma, 1970; Pelli, Palomar, & Majaj, 2004). Because item locations were assigned according to an 8 x 8 grid, this manipulation resulted in particular grid locations being removed from the list of possible distractor locations based on the target location. Displays in the Crowded condition of Experiment 1B were modified to enhance crowding in the local target region. The procedure used to remove crowding in the Uncrowded condition was essentially reversed in the Crowded condition. The locations immediately surrounding the target were given priority when assigning distractor locations for the target quadrant. A visual example of the procedure for the crowding manipulation is provided in Figure 2.

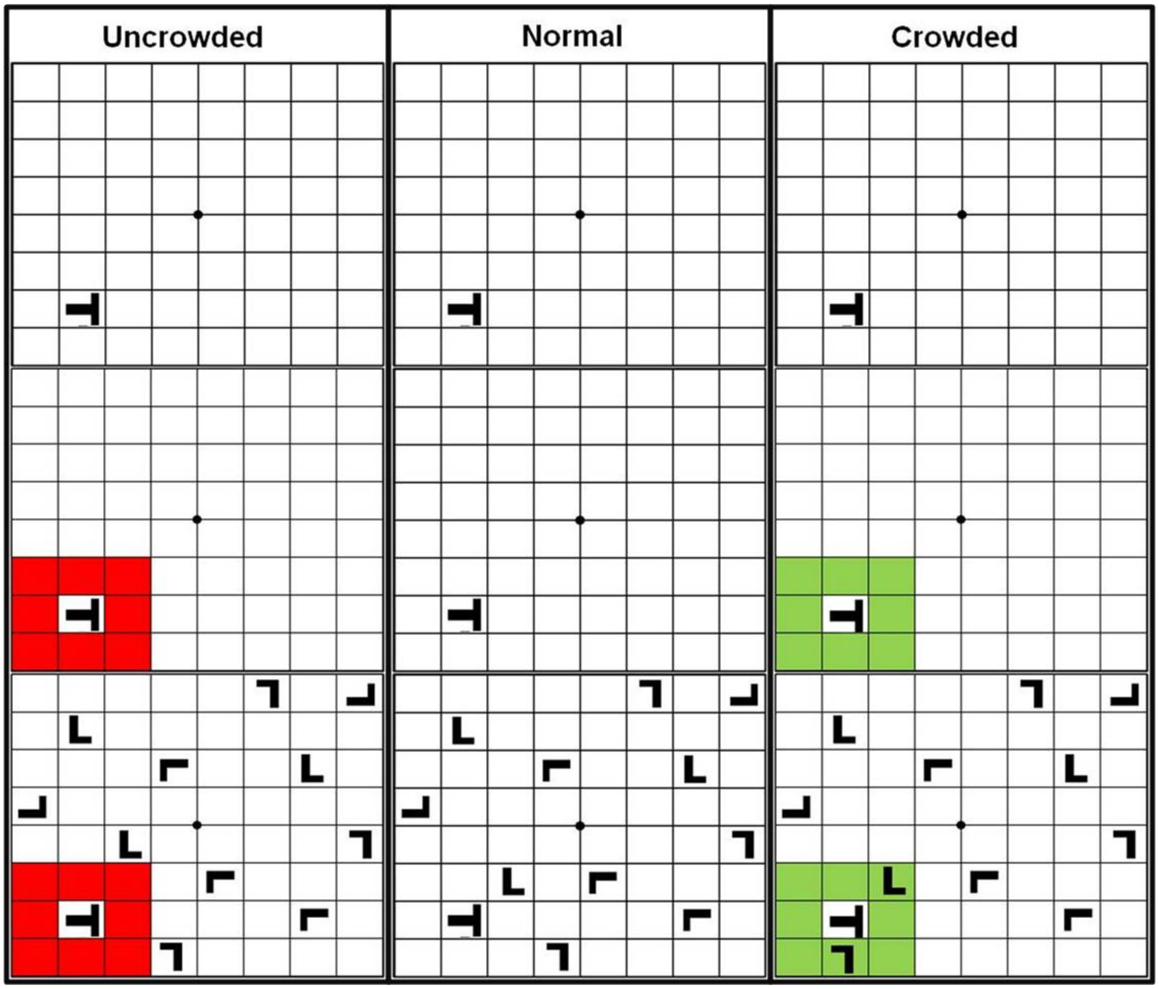

Figure 2. Schematic Example of the Procedure for Generating Displays

In the first column representing the Uncrowded condition, the target is placed in the display and distractors may not appear within the red cells. No constraint on distractor placement is present for the Normal condition in the second column. The final column represents the Crowded condition and distractors appearing in the target quadrant are placed in the green cells.

We utilized a basic model to quantify the amount of crowding occurring in each of the crowding conditions. The mean number of distractors in the local target region increased linearly in the Normal and Crowded conditions, with much higher means at all set sizes in the Crowded condition. No distractors appeared in the local target region in the Uncrowded condition of course, as that was exactly the manipulation. These data are present in Figure 3.

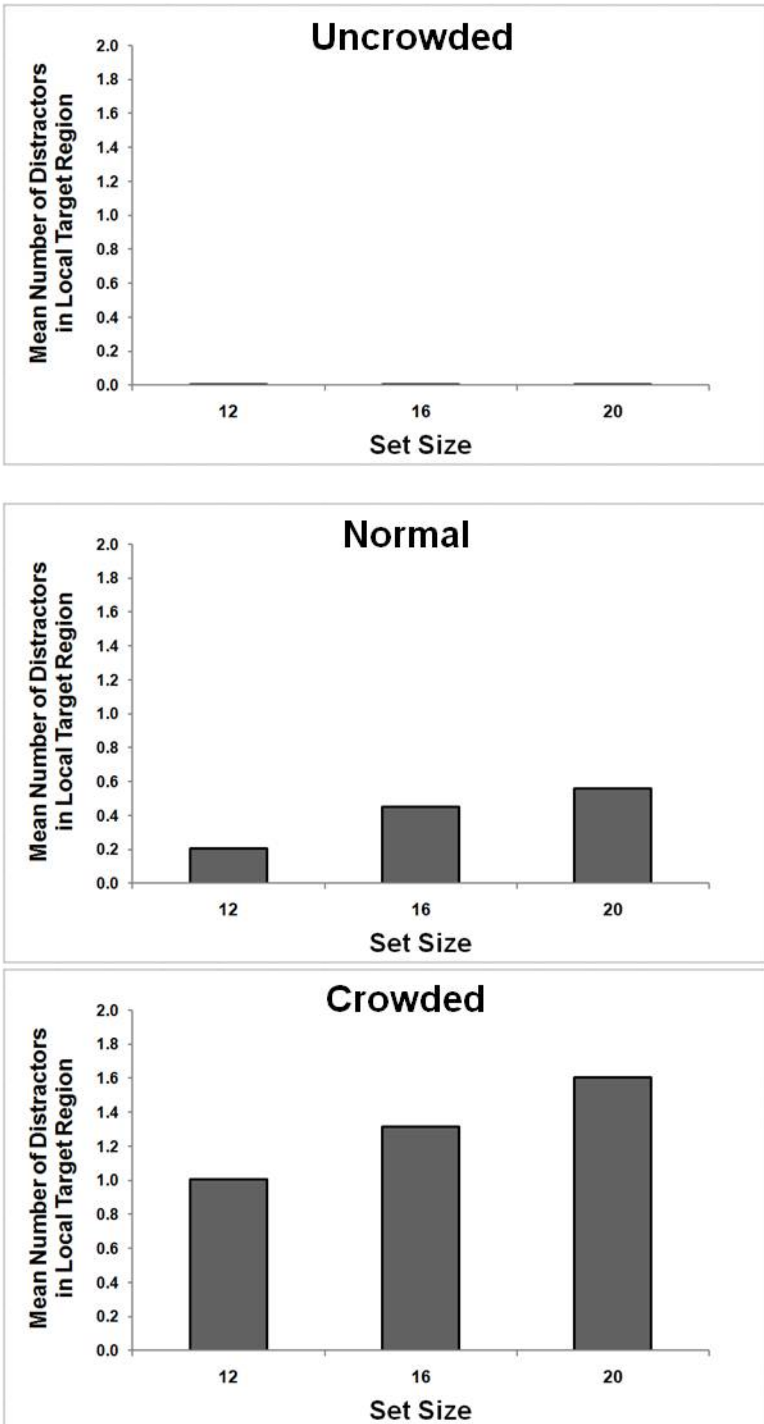

Figure 3. Model Data Quantifying the Amount of Crowding in the Displays

Design and Procedure

A standard visual search task in line with previous contextual cueing experiments was used. Each participant completed a total of 576 experimental visual search trials. An unanalyzed practice block was followed by 24 experimental blocks of 24 trials each. The blocks were collapsed into 8 epochs (3 blocks in each) for analysis. The four main variables of interest were Epoch (1-8), Display Type (Repeated vs. Novel), Set Size (12, 16, 20), and Crowding (Normal vs. Uncrowded or Crowded vs. Uncrowded). Each block was divided into an equal amount of each set size with half of these being Novel displays and half Repeated displays. The trials were further divided such that in Experiment 1A, the trials were split between Normal and Uncrowded displays and in Experiment 1B, the trials were split between Crowded and Uncrowded displays.

Participants completed consent forms and were read instructions adapted from Lleras and Von Muhlenen (2004) prior to beginning the experiment and were not informed of any of the critical manipulations. These instructions were designed to promote a ‘passive’ search strategy which has been demonstrated to be important in eliciting the contextual cueing effect. Participants pressed the spacebar to begin each block. Each trial started with the presentation of a small dot for 750ms at the center of the display for fixation followed immediately by the display containing the stimuli. Participants responded by pressing the ‘z’ or ‘/’ key once the target was located depending on the direction that the base of the ‘T’ was pointing. Following a response, a blank screen replaced the display and error feedback, if necessary, was provided. After a pause of 1000ms, the next trial was initiated automatically. The trial sequence is illustrated in Figure 4. Breaks were provided between each block. Following completion of the experiment, the participants were debriefed and awarded their participation credit. The entire experiment took approximately 45 minutes.

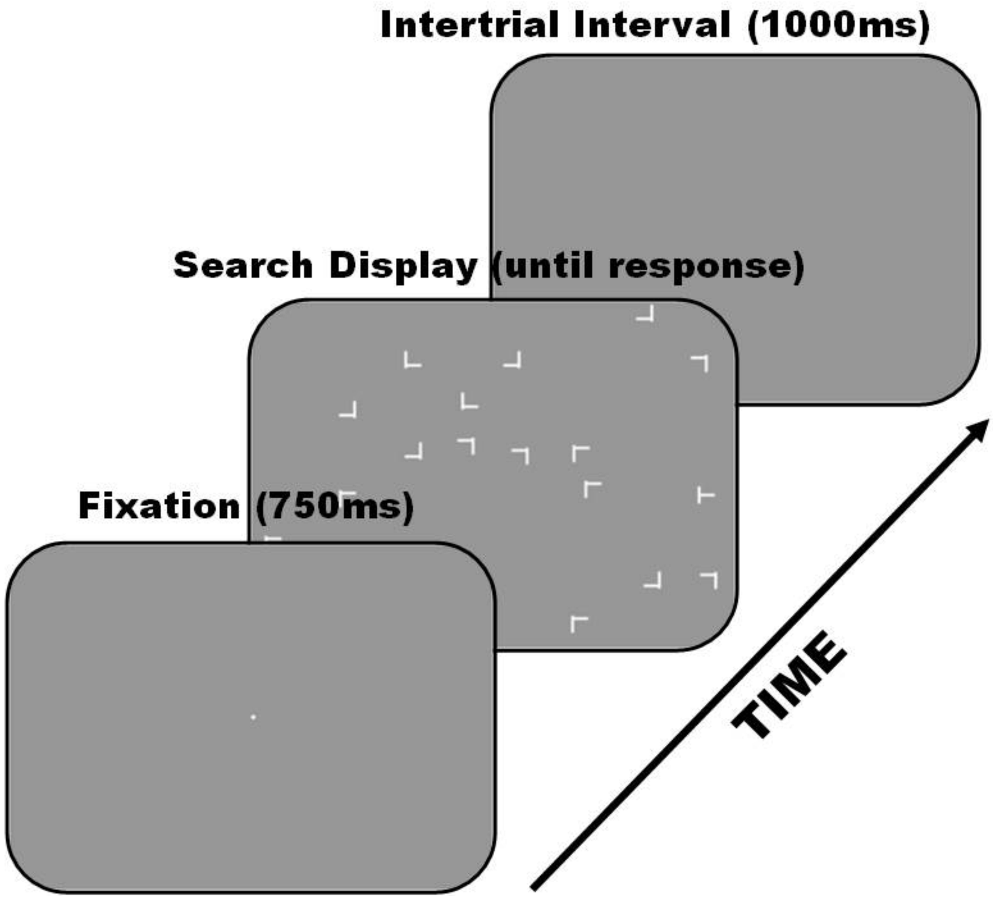

Figure 4. Example of the Trial Sequence

Results

The same exact analysis was conducted for both Experiments 1A and 1B. Incorrect trials as well as any trials where RT exceeded three standard deviations above or below the participant's mean for that condition and block were excluded from all analyses (less than 5% of trials). Participants with less than 95% accuracy were also excluded (N = 13) along with generally non-compliant participants (sleeping, N = 2; reporting complete lack of effort, N = 1). This resulted in sample sizes of 64 and 61 participants for experiments 1A and 1B respectively. In order to ensure the absence of a speed accuracy trade-off, error rates were subjected to an ANOVA with Epoch (1-8), Configuration (Repeated vs. Novel), Set Size (12, 16, 20), and Crowding (Normal vs. Uncrowded or Crowded vs. Uncrowded) as factors. Errors did not correlate with any variables of interest (all Fs < 1.74, ps $> .18$) and will not be discussed further.

These experiments were identical with the exception of the normal and crowded conditions, so we collapsed across the uncrowded condition and the results of both experiments will be presented together. Levene's test indicated that error variance did not differ significantly between the Uncrowded conditions of the two experiments, Fs < 1.5, ps $> .214$.

The primary measure of the magnitude of contextual cueing used in the literature is the difference between the Novel and Repeated conditions collapsed across the last half of the experiment (Chun & Jiang, 1998). A significant contextual cueing effect of 109 ms was obtained in the Normal condition, $t(63) = 3.79$, $p < .001$, indicating the successful replication of previous experiments (see Figure 5a). A significant contextual cueing effect (*M* = 163 ms) was also obtained in the Uncrowded condition, $t(124) = 7.42$, $p < .001$, while no significant contextual cueing effect was obtained in the Crowded condition, $t(60) = 1.21$, $p = 2.33$ (see Figures 5b-c).

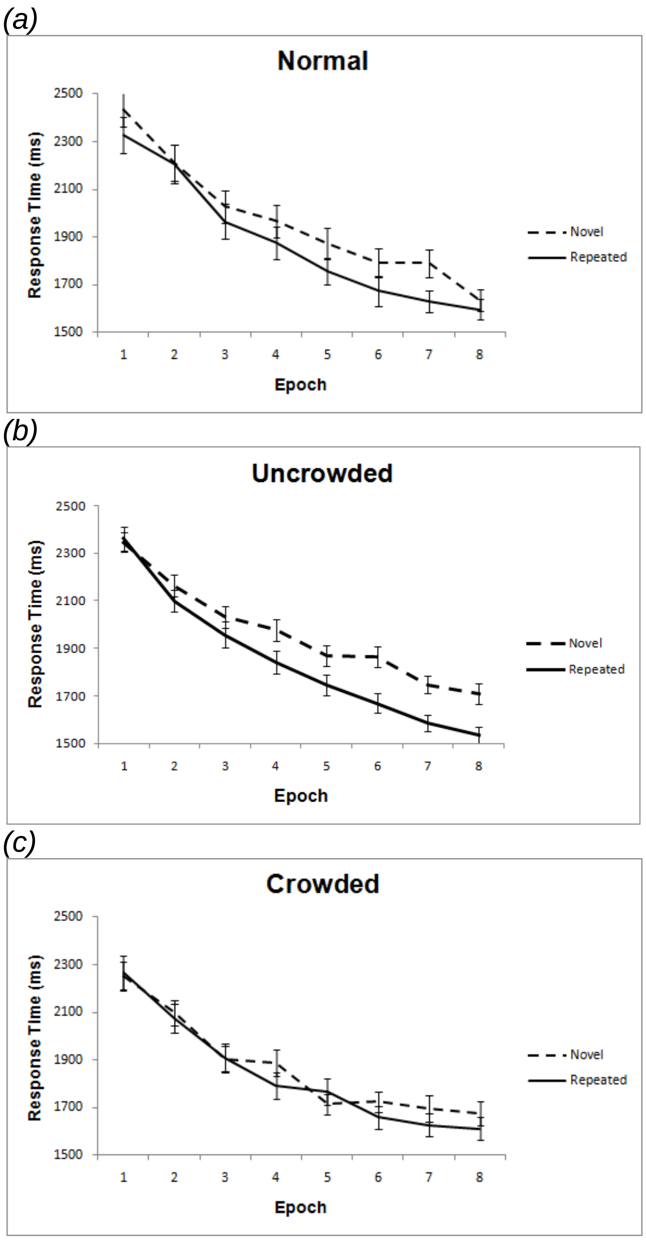

Figure 5. RT Data for Normal, Uncrowded, and Crowded Conditions

The critical analyses for this study concerned the RT x set size search slopes. These were derived from each participant's mean data across the last half of trials. The means for these search slopes appear in Table 1; see Figures 6-8 for the slopes themselves.

Table 1. Mean RT Data as a Function of Display Type and Set Size (SE in parentheses)

Display Type	Set Size 12	Set Size 16	Set Size 20	Overall	Slope
			Normal (*n* = 64)		
Novel	1544.52 (49.35)	1777.34 (59.39)	1999.34 (63.83)	1773.73 (50.87)	56.85 (6.05)
Repeated	1395.66 (46.20)	1707.36 (61.84)	1891.68 (71.09)	1664.90 (47.88)	62.00 (8.06)
			Uncrowded (*n* = 125)		
Novel	1544.14 (31.32)	1781.95 (44.40)	2063.64 (52.73)	1796.58 (37.19)	64.94 (5.43)
Repeated	1433.72 (34.23)	1644.28 (42.60)	1822.30 (50.78)	1633.43 (34.96)	48.57 (5.69)
			Crowded (*n* = 61)		
Novel	1415.17 (32.33)	1678.63 (43.56)	2014.32 (65.51)	1702.71 (39.70)	74.89 (6.64)
Repeated	1407.44 (40.96)	1659.22 (53.35)	1933.41 (71.99)	1666.7 (44.43)	65.75 (8.10)

Novel and Repeated slopes were obtained for, and compared within, each crowding condition (Normal, Crowded, and Uncrowded). No significant slope difference was obtained in either the Crowded, *M* = 9.15 ms/item, *t*(60) = 1.13, *p* = .26, or the Normal condition, *M* = 5.15 ms/item, *t*(63) = .58, *p* = .57.

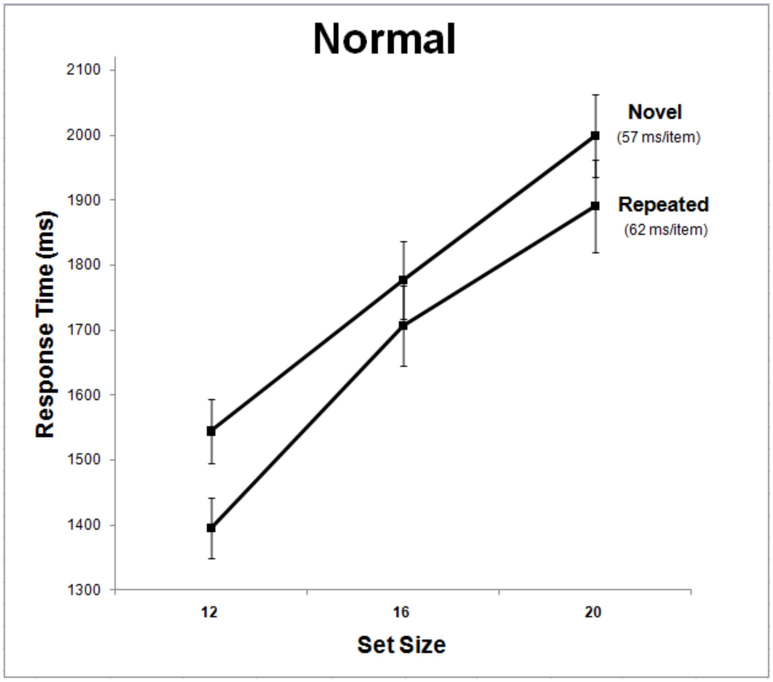

Figure 6. RT x Set Size Search Slopes for the Normal Condition

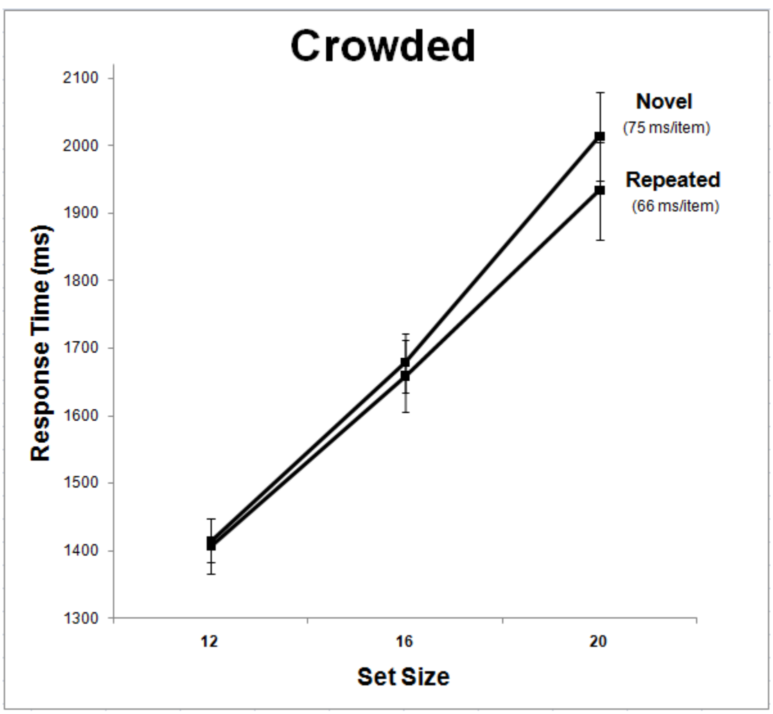

Figure 7. RT x Set Size Search Slopes for the Crowded Condition

However, a significant 25% reduction (over 16 ms/item) from the novel to repeated slope was obtained in the Uncrowded condition, $t(124) = 2.32$, $p = .022$. In addition, a linear trend analysis of the magnitude of the contextual cueing effect across set size in the Uncrowded condition yielded a significant positive linear trend, $F(1,248) = 5.51$, $p = .02$.

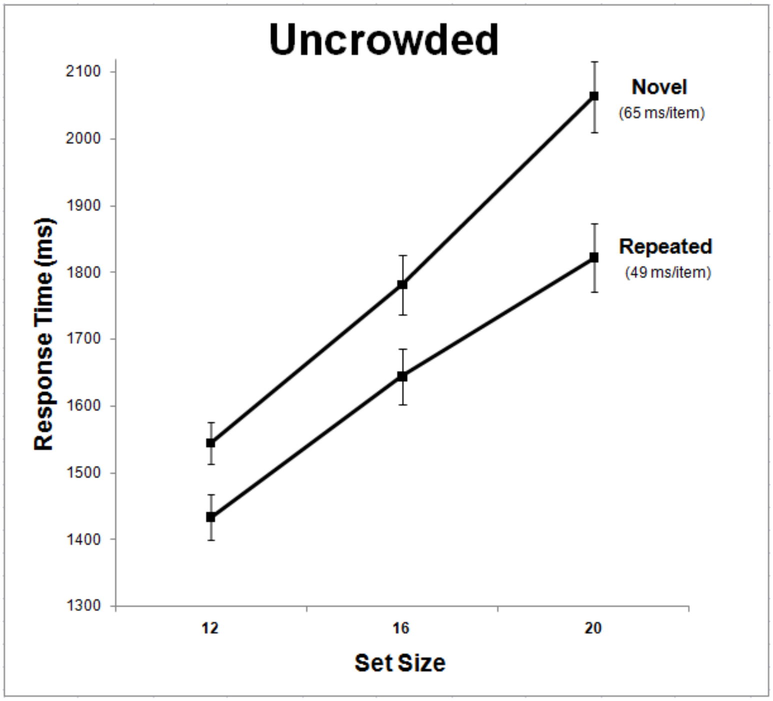

Figure 8. RT x Set Size Search Slopes for the Uncrowded Condition

While these slopes appear unusually large overall, this is likely due to the especially difficult nature of the task we used (offset junctions in distractors) and we would note that the critical factor is the relative difference between the slopes.

In a technique suggested by Kunar & Colleagues (2007), another way to look at the issue is to determine if the slope reduction can account for the magnitude of the contextual cueing effect. In the Uncrowded condition, the effect was about 240 ms at the largest set size, meaning that the slope reduction would have to be at least 240 divided by 20, or 12 ms/item. At more than 15 ms/item, our observed slope reduction easily accounts for the magnitude of the contextual cueing effect.

Discussion

In the present study we investigated the influence of visual crowding on the contextual cueing effect. We hypothesized that crowding of the target impairs the efficacy of attentional guidance in contextual cueing thereby obscuring any improvement in search efficiency visible in behavioral data. Two central findings supported this hypothesis. First, enhanced crowding of the local target region in visual search displays eliminates the contextual cueing effect. Second, displays with completely uncrowded targets result in a significant reduction in search slope from the Novel to the Repeated condition. It is critical to note that both of these manipulations had effects only when the displays were repeated. No significant slope differences were observed between novel displays of the crowding conditions within their respective experiments. Thus, merely crowding or uncrowding the target in a standard visual search task has no significant effect on search performance in unfamiliar displays.

These findings have important theoretical implications for the debate surrounding the mechanism underlying the contextual cueing effect. The associative-learning account (Chun & Jiang, 1998) holds that contextual cueing represents a sort of memory-based attentional guidance and therefore, an improvement in search efficiency. The absence in many contextual cueing studies of a reduction in search slope – the primary measure of search efficiency – from the Novel to the Repeated condition represents a serious obstacle for this account. However, given our findings and the considerable psychophysiological evidence indicating that facilitation is occurring at the search stage, it appears that this slope issue is the product of the fundamentally unique nature of contextual cueing. This uniqueness is highlighted by Johnson and colleagues (2007) when they identify that, “there is no precedent in the memory literature for the hypothesis that activation of an implicit memory can serve as a source of attentional control over the flow of information through the visual cortex.”

With feature-based attentional guidance, early visual processing occurs in parallel across the display prioritizing areas for further processing based on the similarity of their features to those of the target. Depending on the amount of information available to the parallel processes (the quality of the guidance), search may be constrained to varying degree. Because this information is based on the features of the stimuli themselves, when the amount of stimuli present in the display is increased, the guidance derived from those stimuli receives a corresponding increase. That is, the quality of the guidance is constant as set size increases precisely because it is derived from the features of the items themselves. This is in contrast to contextual cueing in which memory is the candidate source of guidance. Unlike simple feature dimensions, memory for scene context constitutes a variable and contingent, albeit useful, source of information for attentional mechanisms. In this case, the assumption of a constant increase in guidance quality along with increases in set size is no longer valid.

Our findings indicate that guidance quality actually decreases as set size increases due to the increased likelihood of crowding. Crowding of the local target region inhibits the contextual cueing effect. When crowding is enhanced, the effect disappears. When crowding is removed, the effect not only increases in magnitude, but search appears more efficient. This suggests that the contextual cueing effect is contingent upon peripheral recognition of the target on repeated trials. We believe that an enhanced likelihood of peripheral target recognition may actually be the primary driver of the contextual cueing effect. In this scenario, a display that has been encountered previously is implicitly recognized upon presentation, after which a unique form of memory-based attentional guidance prioritizes the local target region for processing. If the target can be recognized peripherally, it is fixated directly and a response is initiated. However, if the target is crowded and therefore cannot be peripherally identified, normal bottom-up search takes over. While directly fixating the target would result in greater benefits the larger the set size, it is also less likely to occur on a given trial due to enhanced crowding. This account is supported by much of the previous literature that has addressed the underlying mechanism of contextual cueing.

In their contextual cueing and eye movements study, Peterson & Kramer (2001) observed that the first fixation landed directly on the target more often for repeated than novel displays (11.3% vs. 7.1% respectively). No bias of the initial saccade toward the target location was observed in those trials where immediate localization did not occur, but search nonetheless required fewer fixations. These findings support a spatially accurate guidance mechanism that only occurs on a proportion of trials rather than a constant effect that provides only minimal facilitation (e.g., response facilitation). While the authors attributed the lack of facilitation on many trials to imperfect recognition that could nonetheless occur later in the search process, it could be accounted for just as well by inhibited memory-based guidance on these trials due to crowding of the target. Normal search may dominate while the target is crowded and thus cannot be peripherally identified, but if in the process fixation is made near enough to the target that crowding is reduced, search could still benefit from an increased likelihood of peripheral recognition. While we agree that imperfect recognition likely plays a significant role in reducing the facilitation of contextual cueing, direct evidence for this assertion is lacking and our findings indicate that crowding of the target does exactly that.

In support of our claim that memory-based attentional guidance must compete with normal bottom-up search processes, Lleras & Von Muhlenen (2004) demonstrated that encouraging participants to use an ‘active’ search strategy resulted in no significant contextual cueing in contrast with the robust effect produced by a ‘passive’ strategy. The authors concluded that the influence of memory-based guidance on performance is limited by the search strategy employed rather than a lack of implicit learning. We contend that memory-based guidance must overcome normal search and that promoting an active search strategy supports the latter process while a passive strategy supports the former. Crowding of the target likely acts in much the same way to weaken memory-based guidance in favor of normal search processes. While a particular search strategy has an experiment-wide impact, crowding acts on a trial-by-trial basis.

In conclusion, rather than indicating the absence of increased search efficiency, the steep search slopes observed in contextual cueing experiments reflect more efficient search that occurs less often as set size increases. It appears that performance in a visual search task is facilitated when the displays have been encountered previously, but only if the circumstances allow memory-based attentional guidance to overcome normal, bottom-up search processes. A variety of factors may influence its ability to do so, including previously identified examples like search strategy. We have demonstrated the critical nature of peripheral recognition of the target and the consequences of crowding on the efficacy of memory-based attentional guidance.

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