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Does Contextual Cuing Guide the Deployment of Attention?

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Contextual cuing experiments show that when displays are repeated, reaction times to find a target decrease over time even when observers are not aware of the repetition. It has been thought that the context of the display guides attention to the target. The authors tested this hypothesis by comparing the effects of guidance in a standard search task with the effects of contextual cuing. First, in standard search, an improvement in guidance causes search slopes (derived from Reaction Time × Set Size functions) to decrease. In contrast, the authors found that search slopes in contextual cuing did not become more efficient over time (Experiment 1). Second, when guidance was optimal (e.g., in easy feature search), they still found a small but reliable contextual cuing effect (Experiments 2a and 2b), suggesting that other factors, such as response selection, contribute to the effect. Experiment 3 supported this hypothesis by showing that the contextual cuing effect disappeared when the authors added interference to the response selection process. Overall, the data suggest that the relationship between guidance and contextual cuing is weak and that response selection can account for part of the effect.

Keywords: contextual cuing, attention, guidance, response selection, visual search

In everyday life, people are inundated by a glut of visual stimuli. Visual scenes are often complex, containing a large amount of irrelevant information. In a commonplace search for something like a particular student in an auditorium, observers would be overwhelmed if they were to attempt to attend to every stimulus at once. In response to the inability to process all visual stimuli simultaneously, the visual system has attentional mechanisms that permit individuals to search for the student by deploying attention to one or a few objects at a time out of the crowded world. Given the inherent complexity of the task, the visual system has evolved a variety of mechanisms to optimize this selection process. Many of these mechanisms come under the rubric of attentional guidance (see Wolfe & Horowitz, 2004). Guidance processes speed search by directing attention to items more likely to be targets. Thus, the student is likely to be human-sized and elongated. Attention is guided to objects with those attributes in preference to, for example, small, cubic objects. Spatial configuration of items is a candidate source of guidance. The visual system appears to be sensitive to the predictive value of repeated spatial configurations. In this article, we ask whether this contextual cuing (Chun & Jiang, 1998) is a form of guidance. Our answer will be that contextual cuing is, at best, a very weak form of guidance and that there are other mechanisms involved in the beneficial impact of repeated configuration on response times.

It has long been known that context speeds object recognition (Biederman, 1972). For example, one would be faster to name a potato masher on a kitchen countertop than the same implement on a workbench. Similarly, a student easily recognized in the classroom might be difficult to place if one ran into her at the mall. But does context affect one's ability to search for a specific target? Intuition suggests that it should be easier to find the potato masher if it were habitually stored to the right of the fridge than if it could appear anywhere in the kitchen and that one would have a better chance of finding our student if she always sat in the same seat than if one had to search the entire auditorium.

Research by Chun and Jiang (1998, 2003) seemed to confirm these intuitive predictions. They demonstrated that the spatial layout of a search display could influence how quickly participants found a target. In a series of studies, they found that if the target item was embedded in an invariant configuration that was repeated across the experiment, reaction times (RTs) to find the target were quicker than when the target item appeared in a novel or unrepeated configuration; this is the basic contextual cuing phenomenon. Further research has found that contextual cuing can be based on implicit memory, is learned after only five repetitions of the display (Chun & Jiang, 1998), and can persist for up to 1 week (Chun & Jiang, 2003).

In their initial article, Chun and Jiang (1998) suggested that contextual cuing occurs because the visual context can guide spatial attention toward the target. In fact, the notion that contextual cuing helps guidance is repeated throughout the literature

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(e.g., Chun, 2000; Chun & Jiang, 1998, 1999; Chun & Jiang, 2003; Endo & Takeda, 2004; Hoffmann & Sebald, 2005; Jiang & Chun, 2001; Jiang & Leung, 2005; Jiang, Song, & Rigas, 2005; Jiang & Wagner, 2004; Lleras & Von Mühlenen, 2004; Olson & Chun, 2002; Tseng & Li, 2004). This fits with our intuitive notion that when people know where to expect a target, they do not need to search too much but instead, taking our example of looking for a student in an auditorium, deploy their attention directly to the expected seat. However, one might observe faster search times without improving the search process at all. For example, it might take just as long to search for a target in a repeated configuration, but once found, the target in the expected location might be recognized and/or responded to more quickly, just as the student is more readily identified in the classroom than in the mall. In this article, we ask whether contextual cuing really guides the search process itself—making the search more efficient—or whether other factors such as facilitation in response selection play a part in contextual cuing.

RTs in visual search experiments can be affected by any processing stage between the retina and the hand (Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002). In order to isolate the cost of search proper from perceptual, decision, and response factors, researchers studying search behavior in the RT domain typically vary the number of items (set size) and fit a line to the RT × Set Size function. The slope of this line can be taken as a measure of the efficiency of search, whereas nonsearch factors, such as initial perceptual processing and response selection processes, contribute to the intercept. A wide range of slopes has been observed in the literature (Wolfe, 1998). A slope of 0 ms/item shows that RT is independent of the number of distractors, indicating that attention is directed immediately to the target. Such highly efficient search is characteristic of feature search (Treisman & Gelade, 1980), in which the target differs markedly from distractors along some basic feature dimension, such as search for a red letter among green letters or for a horizontal bar among verticals (see Wolfe & Horowitz, 2004, for a review). In less efficient search tasks, each additional distractor is associated with an increase in mean RT. For example, conjunction search, in which the target is defined by a combination of features each of which is present separately in the distractors (e.g., finding a red vertical bar among red horizontals and green verticals), is generally less efficient than feature search (Treisman & Gelade, 1980), with slopes averaging 10–15 ms/item (Wolfe, 1998). More difficult spatial configuration searches, in which the target is defined by the spatial arrangement of elements (e.g., finding a digital 2 among digital 5s) might produce slopes of 20–40 ms/item (Wolfe, 1998). Many differences in search efficiency can be attributed to differences in guidance. To give one example, the inefficient search for a 2 among 5s becomes more efficient if it is a search for a red 2 among red and black 5s. Attention would be guided to red items, reducing the effective set size.

If contextual cuing were the result of guiding attention to the target, there are several predictions we could make based on the extensive visual search literature. For example, contextual cuing ought to result in improved search efficiency, so we should see a decrease in search slope over the course of a contextual cuing experiment. To take an extreme example, if contextual cuing produced perfect guidance, attention would go directly to the target item and the search slope would drop to zero. Although such perfect guidance is unlikely, search slopes for repeated displays should, at the very least, be markedly reduced compared with those from unrepeated displays. We tested this prediction in Experiment 1 and found little, if any, improvement in search efficiency.[1]

If guidance cannot account for the whole contextual cuing effect, then what can? Experiments 2 and 3 tested the hypothesis that response priming contributes to contextual cuing. Experiment 2 showed that small but reliable contextual cuing effects occur even in tasks when there is already perfect guidance (i.e., displays with a single item and feature search tasks). However, contextual cuing disappeared in these tasks when we introduced interference at the level of response selection (Experiment 3). Taken together, these experiments support a role for response factors in contextual cuing. We conclude that several factors, including but probably not limited to response selection, contribute to contextual cuing. Attentional guidance makes, at best, a small contribution.

Experiment 1

If the benefit found in contextual cuing experiments is a result of improved attentional guidance, then we would expect to find an improvement in search efficiency when the display was repeated as well as a benefit in RT. Previous contextual cuing studies, with the exception of Chun and Jiang (1998), have not varied set size and so could not measure search efficiency. Here we ran a contextual cuing experiment in which set size varied from 8 to 12 items, allowing us to compute the RT × Set Size slope.

Method

Participants. Twelve observers between the ages of 18 and 55 years served as participants. Each participant passed Ishihara's Tests for Color-Blindness (Ishihara, 1980) and had normal or corrected-to-normal vision. All participants gave informed consent and were paid $10/hr for their time.

Apparatus and stimuli. This experiment and all following experiments were conducted on a Macintosh G4 computer using MATLAB 5.2.1 (The MathWorks, Natick, MA) software with the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The distractor items were *L* shapes presented randomly in one of four orientations (0°, 90°, 180°, or 270°). The target item was a *T* shape rotated 90° either to the left or to the right with equal probability. There was always a single target present. A blue dot at the center of the screen served as a fixation point. The background color of the screen was a uniform gray. Three black concentric circles surrounded the fixation point with diameters of 9.5°, 15.5°, and 25° visual angle. Sixteen black lines radiated out from the fixation point roughly equidistant from one another to form a radial lattice. On every trial, either 8 or 12 (depending on the set size) circular placeholders appeared at the conjunctions between the concentric

[1] Chun and Jiang (1998) found that search slopes did become more efficient across time. However, slopes for their spatial configuration task never reached the efficiency of feature or even conjunction searches, showing instead a modest improvement from 40 ms/item to a still inefficient 30 ms/item. To our knowledge, no other contextual cuing experiment could measure slope, because none varied set size. However, several studies in our lab (see Experiment 1 and Figure 4) have failed to replicate even the modest effect observed by Chun and Jiang (1998).

circles and the spokes. To compensate for the decline in visual acuity with distance from the fixation point, we increased the size of the place-holding circles and of the *T*s and *L*s with eccentricity. Those on the closest concentric circle were 2° in diameter, those on the middle concentric circle were 3.3° in diameter, and those on the furthest concentric circle were 5.4° in diameter.

All stimuli were made up of two lines of equal length (forming either an *L* or a *T*) and appeared within the circular placeholders. Stimuli enclosed in the smallest placeholders subtended a visual angle of 1° × 1°, those enclosed in the middle placeholders subtended 1.5° × 1.5°, and those enclosed in the largest placeholders subtended 2.5° × 2.5°. A tone sounded at the start of each trial, at which point the items appeared on the screen. The color of the items and the placeholders varied for each participant (either yellow, red, blue, orange, cyan, green, purple, or white) but remained constant throughout the experiment. Participants were asked to respond to the direction of the target letter *T* by pressing the letter *A* if the stem of the *T* was pointing left and *L* if the stem of the *T* was pointing right. Error feedback was given after each trial. Example displays are shown in Figure 1.

Procedure. Participants were given a practice block of 10 trials, followed by 512 experimental trials divided into 8 epochs of 64 trials. Approximately half of the trials in each epoch had a set size of 8. The remaining trials had a set size of 12.

Within each set size, for Epochs 1–7, approximately half of the trials had fixed placeholder configurations that were repeated throughout the experiment (predictive displays). These consisted of four fixed displays that were repeated four times within an epoch for each set size. Overall, each repeated display was shown approximately 28 times throughout the experiment. The other half of the trials had a novel configuration that was generated at random. In order to ensure that participants were not simply learning absolute target locations from the predictive displays, in the random displays, we had targets appear equally often in four randomly selected locations, but these appearances were not correlated with any pattern of distractor locations. In Epoch 8, the absolute target locations for predictive and random trials remained the same, but all configurations were now made random, so that the context was no longer predictive on any of the trials. This was implemented as a secondary check to make sure any benefit observed for predictive displays was due to the learning of display context rather than to the learning of the absolute target locations. If participants were learning the context, then Epoch 8 should produce slower RTs than Epoch 7, even on trials in which the target locations were identical to those used in the predictive displays of Epochs 1–7.

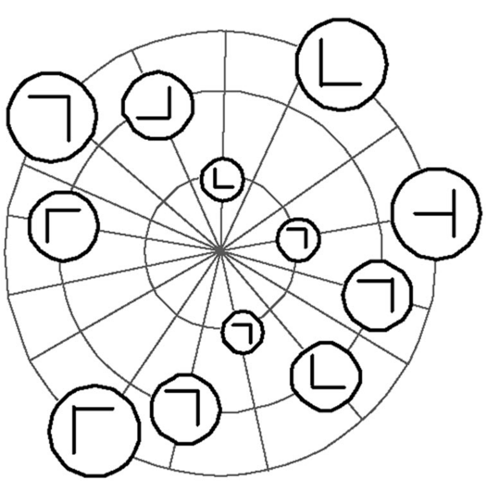

Figure 1. Example displays for Experiment 1.

Data analysis. In the literature, there have been many ways to formally define contextual cuing. Chun and Jiang (1998) suggested that the contextual cuing effect should be measured as the difference between predictive and random configurations across the last three epochs (see also Jiang, Leung, & Burks, 2005; Kunar, Flusberg, & Wolfe, 2006a). This procedure focuses on the asymptotic benefit for having learned a predictive context over a random one. Following their reasoning, we collapsed the data across the last three predictive epochs (here Epochs 5–7) and used this as our standard measure of contextual cuing.

Results and Discussion

Figures 2a and 2b show RTs for both predictive and random configurations for Set Sizes 8 and 12, respectively. RTs below 200 ms and above 4,000 ms were removed. This led to the removal of less than 1% of the data. Examining the RTs, we see that both set sizes showed a contextual cuing effect. For Set Size 8, there was a main effect of configuration and epoch (for Epochs 1–7), in which RTs in the predictive display were faster than those in the random display, $F(1, 11) = 12.2$, $p < .01$, and RTs became faster over time, $F(6, 66) = 2.3$, $p < .05$. There was also a significant Configuration × Epoch interaction, $F(6, 66) = 3.4$, $p < .01$. RTs decreased more across epoch when the display was predictive than when it was random. Comparing the predictive RTs between Epoch 7 and Epoch 8 (in which the predictive configurations were no longer valid), we see that RTs increased when the configuration was no longer predictive, $t(11) = 3.0$, $p < .05$. This finding suggests that it is the context that is important rather than the absolute target locations.[2] When we collapsed the data across Epochs 5–7, the results showed a positive contextual cuing effect: Predictive RTs were 152 ms faster than random ones, $t(11) = 3.8$, $p < .01$.

A similar pattern could be seen for Set Size 12. Here there was a main effect of configuration and epoch (for Epochs 1–7), in which RTs in the predictive display were faster than those in the random display, $F(1, 11) = 23.3$, $p < .01$, and RTs became faster over time, $F(6, 66) = 3.4$, $p < .01$. However, there was no Configuration × Epoch interaction. Collapsing the data across Epochs 5–7 again showed a valid contextual cuing effect. RTs for predictive trials were 174 ms faster than those for random trials, $t(11) = 4.2$, $p < .01$.

Overall error rates were quite low at 3%. There was a significant effect of configuration, $F(1, 11) = 5.2$, $p < .05$; random trials showed a higher error rate than predictive trials. None of the other main effects or interactions proved reliable.

The RT data for both set sizes showed a reliable contextual cuing effect. For present purposes, the critical question is the

[2] This same general pattern occurs in Experiments 2a and 2b reported here; however, in the interest of saving space, we do not report these statistics further.

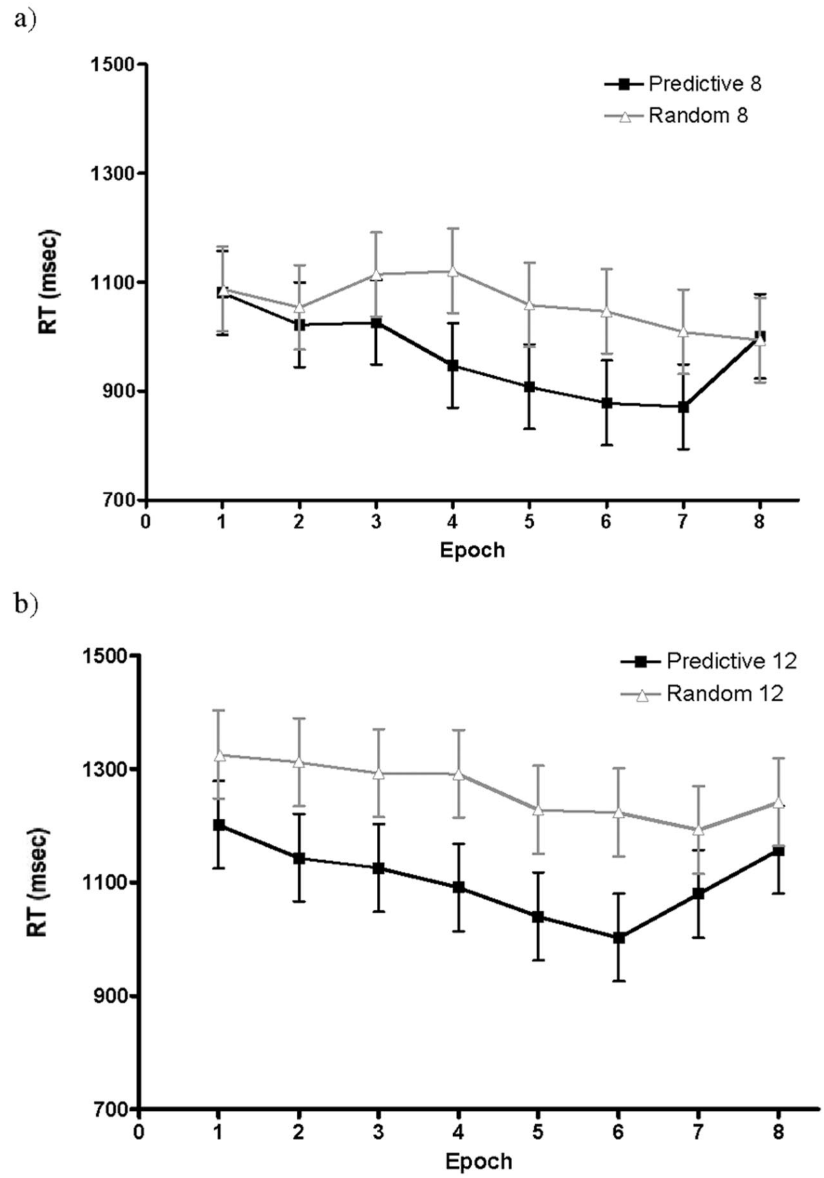

Figure 2. Mean correct reaction times (RTs; ms) for each condition over epoch in Experiment 1. In Epoch 8, all displays are random. Error bars represent the standard error.

effect of contextual cuing on search slope. Slopes for predictive and random displays are shown as a function of epoch in Figure 3. Although there may be some effect, it is not very robust and certainly never yields efficient search for contextually cued targets. There was a main effect of context. Over Epochs 1–7, search slopes were more efficient when the displays were predictive than when they were random, $F(1, 11) = 6.5$, $p < .05$. The effect of epoch was not reliable, $F(6, 66) = 0.4$. Nor was there a reliable Condition × Display Size interaction, $F(6, 66) = 0.7$. If we take our standard measure and collapse the data across Epochs 5–7, there was no contextual cuing effect, $t(11) = 0.6$. If anything, more learning makes the contextual cuing effect on slope less reliable.

Another way to look at this question is to see whether the difference in slope between predictive and random displays can account for the size of the contextual cuing benefit. For example, at Set Size 12, contextual cuing speeded responses by 174 ms (as calculated from Epochs 5–7). In order to account for an effect of this magnitude, slopes in the predictive case would have to be 174/12 or 15 ms/item shallower than in the random case. The observed slope difference, however, was only 5 ms/item (and not reliably different from 0 ms/item). It seems that guidance on its own cannot account for the contextual cuing effect.

If there was any effect of contextual cuing on search efficiency, it was very modest. Instead of seeing a marked improvement in search efficiency, search slopes from repeated displays hovered around 30 ms/item, suggesting, at best, that observers can only eliminate a few items from search.[3] This is similar to data reported by Chun and Jiang (1998). Because it is hard to interpret essentially negative findings, over the course of our research we have replicated this experiment nine other times (see Figure 4). Table 1 gives a brief description of each of the nine new experiments. None of these experiments yielded a reliable difference between predictive and random slopes (again collapsing the data across Epochs 5–7, although two experiments did show a marginal benefit, $p = .09$ in both cases). Furthermore, unlike Experiment 1, eight out of nine of these new experiments showed that there was no reliable main effect of predictive versus random configuration on slope (see Table 1). This again suggests that there was little guidance benefit from having a repeated display. A meta-analysis across all 118 participants in all 10 experiments showed that the overall RT contextual cuing effect (as measured from the last three epochs) for Set Size 12 was 172 ms. Using the logic introduced above, we would predict a 14.4 ms/item slope advantage for the predictive displays, if guidance were to account for the contextual cuing effect. However, the average observed benefit was only half this at 6.9 ms/item (again not reliably different to 0 ms/item), $t(117) = 1.4$. Predictive displays produce, at best, weak slope benefits. Guidance seems to account for, if anything, only a small part of the contextual cuing effect.

Learning appeared rapidly over the first few epochs in Experiment 1 (see Figure 2b). Therefore, one could argue that any slope difference should have emerged early on—perhaps over the first few repetitions. In fact, Chun and Jiang (1998) reported that learning could occur within the first two repeats of a display. To investigate this possibility, we compared the data over the first four repetitions (Block 1) and the next four repetitions of the display (Block 2). If learning occurred after a few trials and resulted in improved guidance, we would expect to find a slope benefit within the first few blocks. However, we did not. There was no difference between search slopes for predictive trials versus random trials for either Block 1, $t(11) = 1.2$, or Block 2, $t(11) = 1.6$. Thus, even if learning occurred early on in the experiment, this did not result in improved search slopes. Even if we extend these analyses to look at search slopes across all subsequent blocks (i.e., groups of four successive predictive displays vs. random displays), we see that throughout the experiment, there was no reliable benefit (all ts $<$ 2.0). Furthermore, a meta-analysis on all 10 experiments shown in Figure 4 found no effect of predictive versus random search slopes for Blocks 1, $t(117) = 1.0$, or 2, $t(117) = 0.1$. This analysis argues that the contextual cuing effect involves, at best, a limited improvement in guidance.

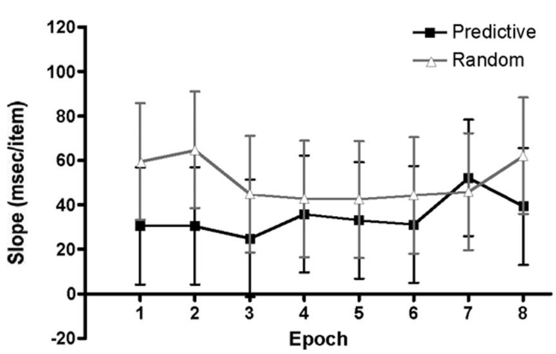

Figure 3. Search slopes (ms/item) for each condition over epoch in Experiment 1. In Epoch 8, all displays are random. Error bars represent the standard error.

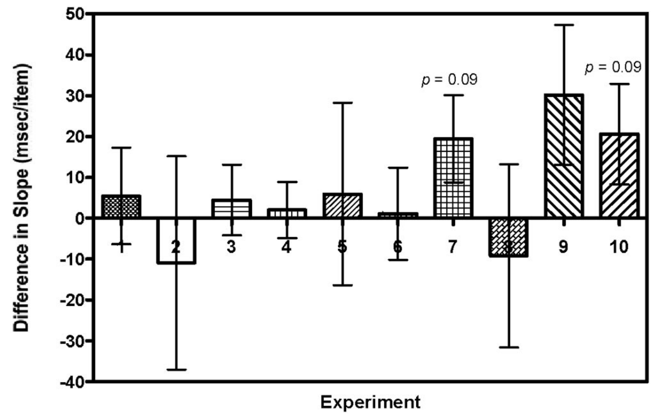

Figure 4. Ten experiments showing that there is little difference between predictive and random search slopes within contextual cueing studies. The data for Experiment 1 in this figure are from Experiment 1 in the present article. Error bars represent the standard error.

Perhaps we did not find an effect on search slope because of differential contextual cuing effects across set size. It has been suggested that contextual cuing does not occur in crowded displays (e.g., see Hodsoll & Humphreys, 2005), as the context loses some of its distinctiveness. If this were the case, and a display of Set Size 12 was less distinct than Set Size 8, there would be less contextual cuing with the former than the latter. Thus, a reduction in distinctiveness with increasing set size might offset the benefit of guidance, leading to no net change in slope. We find this explanation unlikely. In Hodsoll and Humphreys's (2005) experiments, displays of Set Size 10 produced strong contextual cuing, whereas displays of Set Size 20 did not. Displays of Set Size 12 have been shown to produce a robust contextual cuing effect throughout the literature, indicating that they are seen to provide unique and distinct contexts. The difference in distinctiveness between Set Size 8 and Set Size 12 seems unlikely to offset any but the weakest of potential guidance effects. However, in the absence of further data, we cannot rule out this possibility.

If factors other than attentional guidance were involved in contextual cuing, then we would expect to see reliable differences in intercepts between predictive and random displays. Intercept effects are thought to reflect perceptual processes and/or response selection processes. Figure 5a shows intercept effects across epoch for all of the 10 experiments reported above, and Figure 5b shows the difference in predictive versus random displays over the last three epochs. As can be seen, there was a clear difference between predictive and random intercepts, reflected in a reliable main effect between predictive and random displays, $F(1, 117) = 4.3$, $p < .05$,

[3] This agrees with work by Brady and Chun (2006), who suggested that as contextual cuing emerges as a result of learning the association between the target and a few local distractors, the reduction in search slopes should be limited.

Table 1
A Brief Description of the Nine New Experiments Investigating the Effect of Contextual Cuing on Slope and RT in Figure 4

Experiment	*N*	Set sizes	Stimuli	Background lattice	Main effect of configuration (slope)	Main effect of configuration (RT)
2	12	8, 12	Letters	Yes	No	Marginal
3	8	8, 12	T vs. L	No	No	Yes
4	12	4, 8, 12	T vs. L	Yes	No	Yes
5	12	8, 12	V vs. H	Yes	No	Yes
6	12	8, 12	V vs. H	Yes	No	Yes
7	12	8, 12	T vs. L*	Yes	Marginal	Yes
8	12	8, 12	V vs. H	Yes	No	Yes
9	13	8, 12	T vs. L	Yes	No	Yes
10	13	8, 12	V vs. H	Yes	Yes	Yes

Note. RT = reaction time. Letters = stimuli were heterogeneous letters; the task was to respond to the mirror reversed letter. T vs. L = the task was to respond to the orientation of the letter *T* among rotated distractor *L*s (this was the same task as that of Experiment 1). T vs. L* = the task was to respond to the color of the *T* among *L*s; all stimuli were randomly colored red or green. V vs. H = the task was to report whether the target was a vertical or horizontal line; the distractors were oblique lines orientated either 30°, 60°, −30° or −60° of the vertical.

and a significant difference across the last three epochs, $t(117) = 2.4$, $p < .05$. These data suggest that processes other than guidance must account for some portion of the contextual cuing benefit. Presumably these will be either a facilitation of early processing stages or a facilitation of response selection processes. Experiment 3 investigated the role of this latter component, whereas Experiment 2 explored whether a contextual cuing effect can still occur when guidance is already optimal.

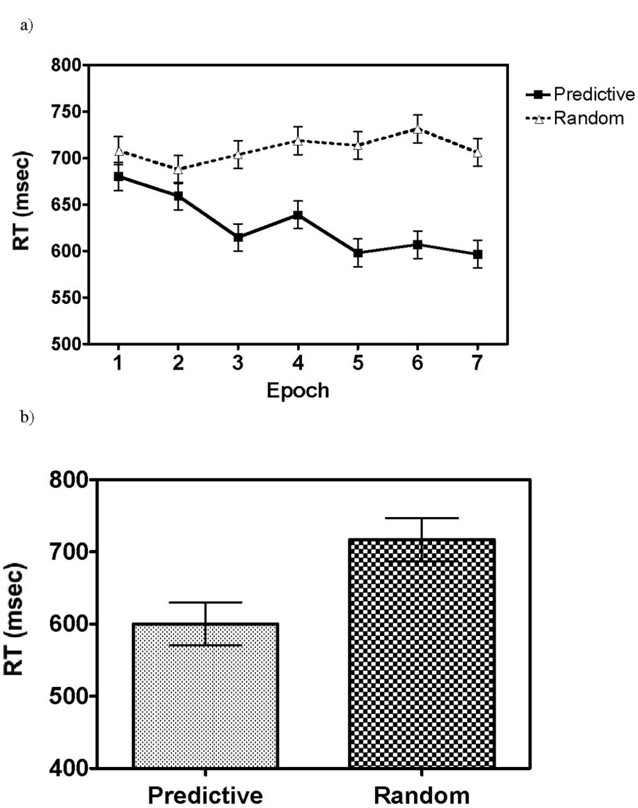

Figure 5. Intercept effects (ms) for predictive and random displays across all 118 participants tested in Figure 4 for each epoch (a) and over the last three predictive epochs (b). Error bars represent the standard error. RT = reaction time.

Experiment 2a

If contextual cuing improved search by guiding attention to the target, then it should be of little use when the guidance signal is already strong enough to attract attention to the target location with near certainty. In Experiment 2a, a single letter was presented on each trial. Empty circular placeholders provided the context. There were no distractor items. In this case, standard guidance should direct attention straight to the target. Any guidance by contextual cuing would be redundant.

Method

Participants. Twelve observers between the ages of 18 and 55 years served as participants. Each participant passed Ishihara's Tests for Color-Blindness (Ishihara, 1980) and had normal or corrected-to-normal vision. All participants gave informed consent and were paid $10/hr for their time.

Apparatus and stimuli. The apparatus and stimuli were the same as in Experiment 1, except that 12 placeholders were presented on every trial, and placeholders and the target were white for all participants.

Procedure. The search task was the same as in Experiment 1. There were 10 practice trials followed by 512 experimental trials, divided, for analysis purposes, into 8 epochs of 64 trials. Approximately half of the trials in each epoch had a set size of 1, in which the target appeared in one of the placeholders, whereas the remaining placeholders were empty (i.e., no distractor items). The remaining trials had a set size of 12, in which the target was in one placeholder and distractors filled the remaining 11 placeholders. An example of Set Size 1 is shown in Figure 6. The rest of the procedure was the same as that in Experiment 1: Half of the displays from Epochs 1–7 were predictive, whereas the rest were random. In Epoch 8, every display was random.

Results and Discussion

Overall error rates were quite low at 2%, with no significant effects of set size, configuration, or epoch. Neither were any of the interactions reliable. RTs below 200 ms and above 4,000 ms were removed. This led to the removal of less than 1% of the data. Figures 7a and 7b show RTs for predictive and random configurations for Set Sizes 12 and 1, respectively. RTs at Set Size 12 showed a similar pattern to those of Experiment 1. There was a main effect of configuration and epoch, in which RTs to find targets in predictive configurations (for the first seven epochs) were faster than those in random configurations, $F(1, 11) = 51.3$, $p < .01$, and RTs became faster over time, $F(6, 66) = 4.3$, $p < .01$. The Configuration × Epoch interaction was not significant. Collapsing the data across Epochs 5–7 showed a contextual cuing effect: Predictive RTs were faster than random ones, $t(11) = 6.7$, $p < .01$.

For present purposes, the important finding is the small but reliable contextual cuing effect at Set Size 1. There was an RT benefit when the configuration of the display was predictive rather than random, $F(1, 11) = 13.6$, $p < .01$. There was no effect of epoch nor a reliable Configuration × Epoch interaction. Comparing RTs collapsed across Epochs 5–7 (i.e., the last three epochs), however, showed a positive contextual cuing effect. Even when the target was presented in isolation, predictive RTs were faster than random, $t(11) = 4.0$, $p < .01$. We have replicated this effect two other times: Each experiment produced a reliable contextual cuing effect of at least 30 ms (see Figure 8).

Participants should not have had to search for the target at Set Size 1, because there was only a single item, which was quite obvious in the display. However, we cannot verify that guidance was optimal when only one item was on the screen, because search efficiency can only be measured across set sizes.[4] Therefore, however unlikely, it could be argued that participants were searching the background placeholders for the target. In order to investigate this possibility, we conducted a pilot study in which the

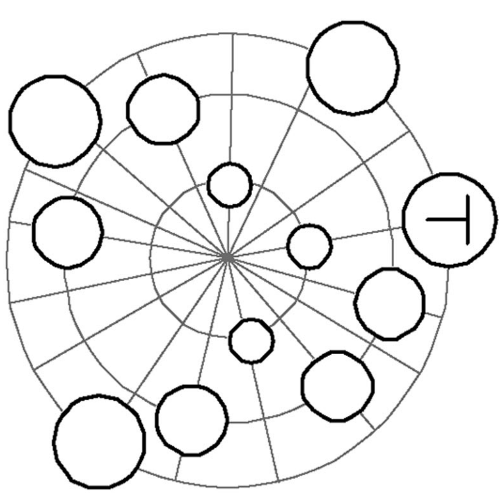

Figure 6. Example displays for Set Size 1 in Experiment 2a.

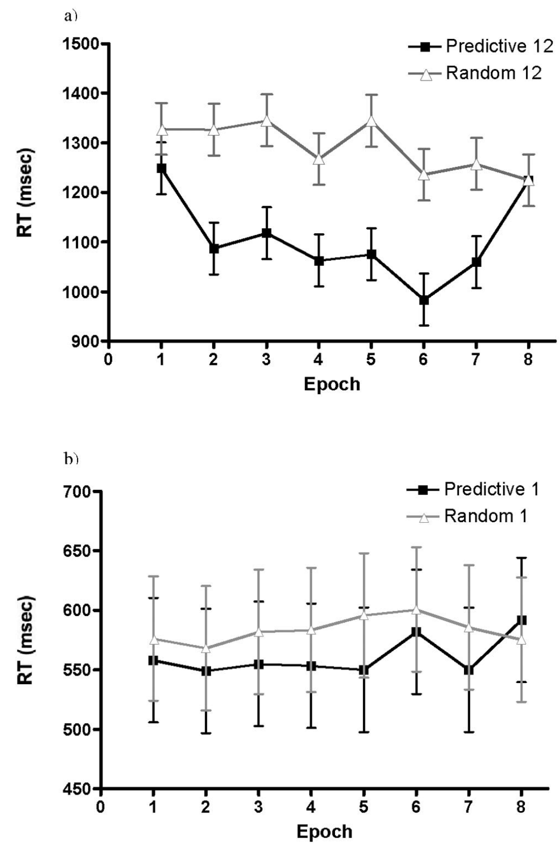

Figure 7. Mean correct reaction times (RTs; ms) for each condition over epoch in Experiment 2a. In Epoch 8, all displays are random. Error bars represent the standard error.

number of placeholders of each condition varied from 8 to 12. If participants were searching each placeholder for the target, then we should expect to find that the RT × Placeholder function would have a slope greater than zero. However, the data show that search slopes did not differ from 0 ms/item for either predictive or random trials (0.2 and 0.9 ms/item, respectively).[5] Furthermore, the RT data replicated the basic contextual cuing finding. Participants were faster at finding a target in a predictive display compared to a random one: $t(9) = 2.1$, $p = .06$, and $t(9) = 1.9$, $p < .09$, for Set Sizes 8 and 12, respectively. Attention was directed to the target item when participants were searching for that target among empty placeholders. Experiment 2b shows converging evidence for this finding using a feature search task. Here the target was so salient that it did not require search to find it and guidance

[4] Please note that we did not derive search slopes in this experiment, as Set Size 1 is a special case that does not reflect search in general. Instead, we relied on the data from Experiment 1 and its replications to address the effects of slope in contextual cuing.

[5] Because we did not run a control condition without placeholders, we cannot rule out the possibility that the placeholders themselves may have slowed RTs. Nevertheless, the relevant point is that participants were not searching among the placeholders; attention was directed immediately to the target.

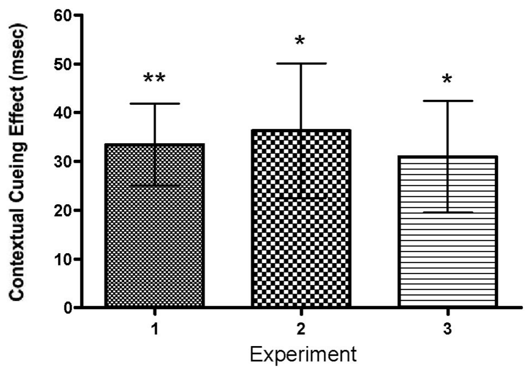

Figure 8. Three experiments showing a valid contextual cuing effect for Set Size 1. The data for Experiment 1 in this figure are from Experiment 2a in the present article. Error bars represent the standard error. * $p < .05$. ** $p < .01$.

was essentially perfect—an assumption that can again be tested by computing the search slope.

Experiment 2b

In Experiment 2b, we repeated the basic contextual cuing design using a feature search task instead of a spatial configuration search task. In feature search, the target is known to pop out of the display without need for any search at all. Treisman (1985) has shown that explicitly precuing the location of a feature target does not improve detection. Therefore, contextual cuing should provide little or no benefit in a feature search task if it serves only to guide attention to the target location.

Method

Participants. Twelve observers between the ages of 18 and 55 years served as participants. Each participant passed Ishihara's Tests for Color-Blindness (Ishihara, 1980) and had normal or corrected-to-normal vision. All participants gave informed consent and were paid $10/hr for their time.

Apparatus and stimuli. The apparatus and stimuli were the same as in Experiment 1, except that the target item, *T*, and its placeholder were always red, whereas the distractor *L*s and their placeholders were always green. The target could be immediately identified on the basis of its color, producing a pop-out single feature task.

Procedure. There were 10 practice trials followed by 512 experimental trials that were divided into 8 epochs of 64 trials for analysis purposes. Approximately half of the trials in each epoch had a set size of 8, whereas the remaining trials had a set size of 12. Within each set size, for Epochs 1–7, half of the trials in an epoch had a spatial configuration predicting the target location, whereas the remaining trials had a random, nonpredictive configuration. In Epoch 8, all of the configurations were randomized.

Results and Discussion

Overall error rates were again low at 4%. There was a significant effect of set size, $F(1, 11) = 10.7$, $p < .01$, with higher errors at Set Size 12 than at Set Size 8. The Configuration × Epoch interaction was also significant, $F(7, 77) = 4.7$, $p < .01$. Errors at Epoch 2 were lower in the predictive condition than errors at other epochs, whereas errors at Epoch 2 were higher in the random condition than at other epochs. None of the other main effects or interactions proved reliable. RTs below 200 ms and above 4,000 ms were removed. This led to the removal of 1% of the data. Figures 9a and 9b show RTs for both predictive and random configurations for Set Sizes 8 and 12, respectively. Examining the overall search slopes for both predictive and random trials, we see that both slopes are shallow (1.4 ms/item for predictive trials; 1.3 ms/item for random trials) and neither slope is reliably different from 0 ms/item.

Although the RT slopes did not differ from 0, there was a significant increase in errors with set size. Does this mean that a speed–accuracy trade-off might be masking steeper slopes? We think not. The effect of set size, although significant, was quite small, amounting to 0.004 additional errors per item. As a rough measure, we can divide RT by accuracy (Townsend & Ashby, 1978), which yields slopes of 4.6 ms/item for predictive trials and 3.5 ms/item for random trials. These values are well within the range of slopes typically observed for feature search (Wolfe, 1998). Thus, we are confident in describing this experiment as a highly efficient pop-out search task. Participants did not have to search the display to find the target.

As in the previous experiment, the important finding is that there is a small contextual cuing effect for this highly efficient search

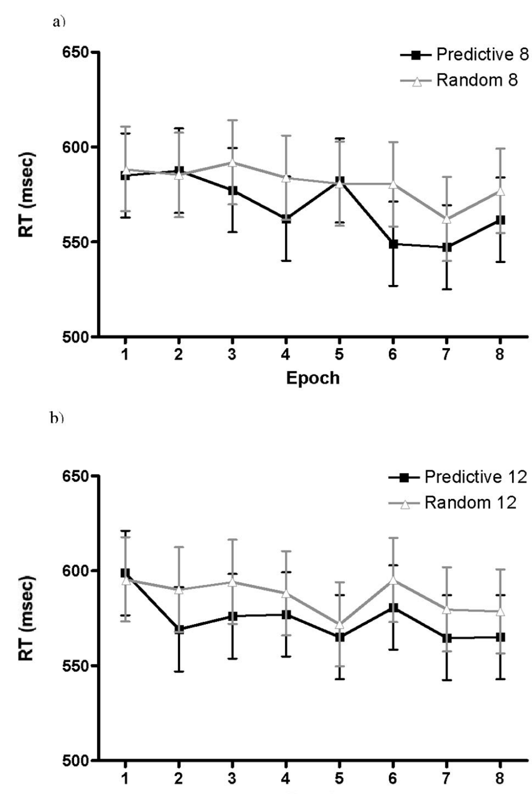

Figure 9. Mean correct reaction times (RTs; ms) for each condition over epoch in Experiment 2b. In Epoch 8, all displays are random. Error bars represent the standard error.

task. Taking Set Size 8 first, we see that although there was no main effect of configuration, epoch, or a reliable Configuration × Epoch interaction, RTs for predictive trials were marginally faster than random ones across Epochs 5–7, $t(11) = 1.9$, $p = .09$. With Set Size 12, we find that overall RTs for predictive configurations were significantly faster than those for random configurations, $F(1, 11) = 9.4$, $p = .01$. There was no effect of epoch or a reliable Configuration × Epoch interaction. However, collapsing the data across Epochs 5–7 showed a positive contextual cuing effect, $t(11) = 2.4$, $p < .05$. Taken together, these results and those from Experiment 2a show that even with a task that requires no search and thus already has a perfect guidance signal, a predictive display still benefited RTs.

The contextual cuing benefit from Experiment 2a and 2b is interesting and could reflect the contribution of any of several factors. For example, it could plausibly reflect a benefit in figure-ground segmentation, early processing stages, or perhaps in response selection (see Experiment 3). It may even occur as the predictive context adds an extra guidance signal to feature search so that the target is found faster. In other words, although guidance is perfect in a color feature search task, perhaps the repeated configuration provides a small but significant additional boost to the color guidance signal, producing the contextual cuing effect in Experiment 2b. If this were indeed the case, the RT benefit should also be seen in other feature searches in which an additional guidance signal has been added. Take, for example, an orientation feature search for a vertical line among horizontal lines. Would the addition of a redundant color signal produce an RT benefit even if search was already highly efficient?

A control study revealed that this is not, in fact, what occurs. In a present–absent search task, participants searched for a vertical line among horizontal lines. On half the trials, the target and distractors were all red. In the remaining trials, half of the distractors were red, whereas the other half were green. If it were possible to add an extra guidance signal to a perfect guidance task, we would expect an RT benefit on the trials with green and red distractors, as participants would be able to use the color information as extra guidance away from green distractors and toward the (red) target. However, the results indicated that there was no difference in RT between the two types of trials. These data suggest that the RT benefit found in the contextual cuing of Experiments 2a and 2b was not due to any extra guidance signal provided by the spatial context.

If the small but reliable contextual cuing effect in efficient search is unlikely to be due to guidance, what processes might benefit from the repeated, predictive context? In the introduction, we suggested that a familiar environment might aid response selection; in particular, it may reduce the threshold needed in order to respond to a target. If individuals implicitly learn that the potato masher is always located next to the fridge in their mother's kitchen, then they might be more ready to respond to the presence of the masher in that location than they would be if they were in a novel kitchen. We explored this possibility in Experiment 3. If contextual cuing really does facilitate response selection, then interfering with response selection would be expected to interfere with the contextual cuing effect seen under perfect guidance conditions.

Experiment 3

Experiment 3 investigated whether the small contextual cuing benefits found in Experiment 2 could have been due to response selection. Here we used a search task in which distractor items elicited either a congruent or an incongruent response (Starreveld, Theeuwes, & Mortier, 2004), a manipulation known to produce interference at the level of response selection (e.g., Cohen & Magen, 1999; Cohen & Shoup, 1997; Eriksen & Eriksen, 1974). If the contextual cuing benefit in Experiments 2a and 2b was due to facilitation within response selection, we would expect to find a similar contextual cuing effect when there was no response selection interference (i.e., when the distractors and target were congruous) but not when interference was added to this process (i.e., on incongruent trials). On the other hand, if contextual cuing occurred at the guidance stage of search or at an early, perceptual stage, then standard additive factor analysis of RT would predict that the effects of a response selection manipulation would be additive with the contextual cuing effect. As shown in Experiment 3, response selection manipulations interact with the contextual cuing effect, suggesting that they occur at the same stage of processing.

Method

Participants. Twelve observers between the ages of 18 and 55 years served as participants. Each participant passed Ishihara's Tests for Color-Blindness (Ishihara, 1980) and had normal or corrected-to-normal vision. All participants gave informed consent and were paid $10/hr for their time.

Apparatus and stimuli. The apparatus and stimuli were the same as in Experiment 2b, except that here the target was either a red *A* or a red *R*. The distractors were either all green *A*s or all green *R*s. There were no placeholders around the target or distractor items. Like Experiment 2b, the target could be immediately identified on the basis of its color, producing a pop-out single feature task.

Procedure. There were 10 practice trials followed by 448 experimental trials that were divided into 7 epochs of 64 trials for analysis purposes. Half of the trials in each epoch were predictive, whereas the other half were random. Within the predictive trials, half of the displays were congruent (a red *A* among green *A*s or a red *R* among green *R*s), whereas the other half were incongruent (a red *A* among green *R*s or a red *R* among green *A*s). For predictive trials, a configuration was always either congruent or incongruent. It was never both. The set size was always 12, and participants had to respond to the question of whether the red letter was an *A* or an *R*.

Results and Discussion

As is typical in experiments of this sort, error rates were higher for incongruent trials (7%) than they were for congruent trials (3%), $F(1, 11) = 15.2$, $p < .01$. However, none of the main effects or interactions were reliable. RTs below 200 ms and above 4,000 ms were removed. This led to the removal of less than 1% of the data.

Figures 10a and 10b show a comparison of contextual cuing effects for congruent and incongruent trials, respectively, whereas Figure 11 shows a comparison of contextual cuing effects over the

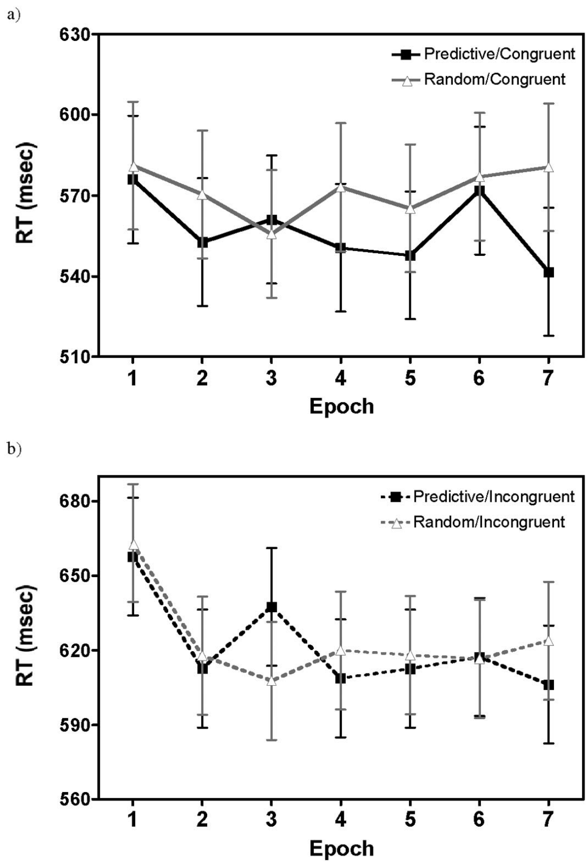

Figure 10. Contextual cuing effects for congruent (a) and incongruent (b) trials over each epoch. Error bars represent the standard error. RT = reaction time.

last three epochs for both the congruent and incongruent trials. Consistent with previous work, there was an overall effect of congruency, $F(1, 11) = 76.1$, $p < .01$. Participants were faster at responding to congruent targets than to incongruent ones. To examine how congruency affects contextual cuing, we computed the contextual cuing effect separately for congruent and incongruent trials. As predicted, there was a contextual cuing effect for the congruent trials. RTs were faster when the display was predictive, $F(1, 11) = 9.9$, $p < .01$, than when it was random. This effect was also observed when we collapsed the data over the last three epochs (Epochs 5–7), $t(11) = 3.8$, $p < .01$. When we examined incongruent trials, however, there was no evidence of a contextual cuing effect. There was no benefit of predictive displays over random displays, either overall, $F(1, 11) = 0.4$, or in the last three epochs, $t(11) = 0.6$. None of the other main effects or interactions were significant.

It is generally accepted that the slowing of RTs in incongruent displays is due to interference at the response selection level (e.g., Cohen & Magen, 1999; Cohen & Shoup, 1997; Eriksen & Eriksen, 1974). Here, all elements in the visual field are processed up to the level in which their associated response has been activated. On incongruent trials, the target item and distractor items activate competing responses, slowing RTs. Experiment 3 demonstrates that interference at the response selection level negates the contextual cuing benefit, at least for feature search displays. This suggests that contextual cuing acts, at least in part, by speeding response*s* to targets in a familiar context.

General Discussion

Chun and Jiang (1998) found that if a target was embedded in a repeated display in which the configuration predicted its location, RTs to find the target were faster than conditions in which the display configuration did not predict the target location. We present three experiments suggesting that attentional guidance cannot account for the entire contextual cuing benefit. Experiment 1 examined the effect of contextual cuing on search slopes. Search slopes are assumed to reflect search efficiency: Improving the attentional guidance signal reduces search slopes. We found that contextual cuing mainly reduced RTs (and intercepts) and produced, at best, a weak reduction in search slopes. Furthermore, we failed to find a reliable search slope difference between predictive and random displays across nine other experiments. Even when the results were pooled across all of these experiments, there was no benefit in search slope. Of note, we found similar effects in a study in which we investigated whether contextual cuing could occur as a result of global background features (Kunar et al., 2006a). Although repeating global background features provided a reliable RT benefit, there was no improvement in search efficiency and hence no evidence for an improvement in attentional guidance.

Experiments 2 and 3 investigated contextual cuing in tasks in which attention was deployed directly to the target item, leaving little role for further guidance by contextual cuing. Nevertheless, Experiment 2a showed that a small contextual cuing effect occurred even when the target was presented in isolation. The same result was obtained when the target was defined by a color singleton in Experiment 2b. Search slopes were not different from 0 ms/item, indicating that the deployment of attention here was already perfect. Thus, the additional benefit found was unlikely to be due to guidance. Adding interference to the response selection stage, however, eliminated contextual cuing (Experiment 3). Here the predictive display could either be made up of distractors eliciting a congruent response to the target or those eliciting an incongruent one. In the incongruent case, the target item and the distractor items both activated competing responses, interfering with response selection. With this interference, the contextual

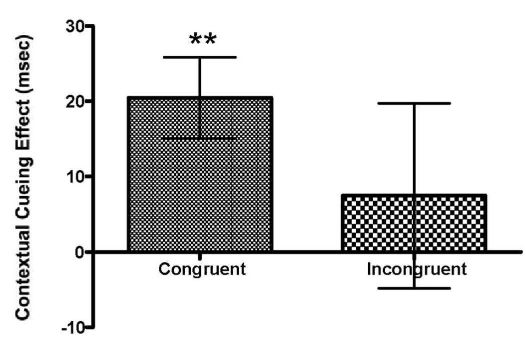

Figure 11. Contextual cuing effects for congruent and incongruent trials over the last three predictive epochs. Error bars represent the standard error. ** $p < .01$.

cuing effect disappeared. The combination of these experiments argues against contextual cuing occurring solely as a result of attentional guidance and suggests a contribution from other factors, including response selection.

A Role for Guidance in Contextual Cuing?

Do these results mean that attentional guidance plays no role in contextual cuing? Although our data suggest that there is little effect on guidance, we do not want to rule out the possibility that contextual cuing could contribute to attentional guidance on some trials. Although their search slopes did not reach that expected by perfect guidance, Chun and Jiang (1998) observed a small but significant slope reduction in their studies. Likewise, 2 of our 10 experiments investigating search efficiency in contextual cuing showed a marginal trend toward search slope improvement (see Figure 4). Peterson and Kramer (2001) also investigated the role of guidance in contextual cuing by measuring eye movements and noting when the eyes went to the target. They found that although contextual cuing increased the proportion of trials in which gaze went to the target on the first saccade from 7.1% to 11.3%, it did not provide perfect guidance on every trial. However, the overall number of saccades necessary to find the target was lower in repeated (predictive) displays than in unrepeated (random) displays. They concluded that recognition of the context is highly imperfect. Sometimes the context is recognized immediately; other times recognition does not occur for some time (if at all). Once the display has been recognized, then guidance can take place. This result argues that contextual cuing does improve guidance on a fraction of trials. However, there must also be other mechanisms that are responsible for the robustness of the contextual cuing effect.

Given enough time, context seems bound to improve search efficiency. Indeed, in recent work, we have found a decrease in slopes in versions of contextual cuing tasks that involve much longer RTs produced by higher set sizes or more complicated display backgrounds (see Kunar et al., 2006a; Kunar, Flusberg, & Wolfe, 2006b, respectively). Similarly, an improvement of search efficiency can be seen if participants are presented with the display context substantially prior to the search stimuli (Kunar et al., 2006b) or when participants are given explicit knowledge about the context (Kunar et al., 2006a). Therefore, it seems that under certain circumstances, context can guide the deployment of attention. However, this form of guidance is relatively slow. In faster search tasks like the ones reported here and in the classic Chun and Jiang (1998) work, the robust contextual cuing effect seems to involve contributions from factors other than guidance.

Recent work by Brady and Chun (2006) offers another reason why any guidance by contextual cuing is likely to be limited. They found that, in contextual cuing, participants only learned the association between the target location and its immediately surrounding distractors (see also Olson & Chun, 2002). In this case, only the local context of the display would be available to guide search. If only a few items in the display serve to guide attention, this might explain why the slope benefit is so small. However, in our experiments, a small (statistically unreliable) slope benefit is accompanied by a large net RT benefit. Thus, the Brady and Chun proposal can only account for part of the contextual cuing effect. Some other factor must be posited to account for the large set-size independent effect.

Response Selection in Contextual Cuing

Our results suggest that there is a response selection component to contextual cuing. How might this work? One possibility is that having a predictive display allows one to respond to the target faster once it has been found. To return to the examples we used in the introduction, it may not be easier to find the potato masher in its habitual place by the fridge, but one may be faster to respond to it if its location is known. This benefit may arise in a number of ways. For example, if the target is in a familiar place, any need for one to double check that the target was found will be eliminated, leading to faster RTs. Similarly, perhaps the response threshold is lowered when the target appears in a familiar context than when it appears in a novel one (see Figure 12). Imagine that an observer normally requires a certain amount of information, *X*, in favor of

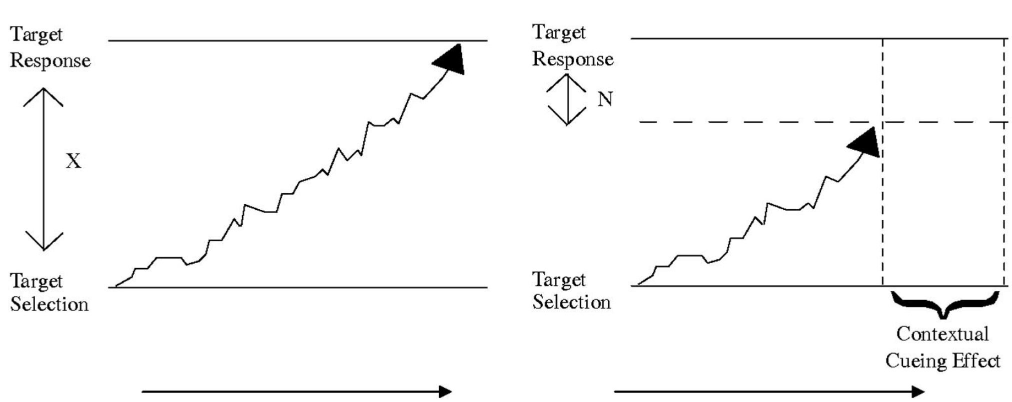

Figure 12. Example of how response selection facilitation may contribute to contextual cuing. Here a repeated display may reduce the threshold needed to respond to the target. Imagine a target requires *X* amount of information before it can be responded to. If the target, however, appears in a habitual location, the quantity of information needed to cross the threshold may be reduced by *N* amount. In this case, the threshold will be crossed sooner, leading to the contextual cuing effect.

a given target identity before committing to that response. If the target appears in a habitual location, however, he or she might reduce this threshold by some amount, *N*. This allows the threshold to be crossed sooner, leading to the contextual cuing effect.

Another possibility is that when the target is processed, the context is to some extent encoded along with the target itself (e.g., Fazl, Grossberg, & Mingolla, 2005). Thus, when the target is attended in a repeated display, the memory trace of prior episodes with similar contexts are retrieved. Because these traces are associated with responses, retrieval speeds response selection or execution.

Floor Effects or Components of Contextual Cuing?

One might ask why the contextual cuing effects for Set Size 1 and feature search tasks are smaller than contextual cuing effects for larger set sizes. For example, in the standard contextual cuing task of Experiment 1, with Set Size 12, the RT benefit was 174 ms. For Set Size 1 and the feature search tasks in Experiments 2a and 2b and the congruent trials of Experiment 3, the benefits were 33 ms, 12 ms, and 20 ms, respectively. There are at least two possible reasons why these latter effects are smaller. First, there may be floor effects. If it is easier to make a response in the pop-out searches, then there will be less room for contextual cuing improvements. Indeed, the surprising finding is that even when RTs were already almost at floor, a predictive display could further reduce response times. A second possibility may be that these small effects reflect response selection factors alone, which are only partly responsible for the contextual cuing benefit. When participants have to search through larger set sizes, repeated displays may recruit additional processes (these could be early perceptual processes; see below). Alternatively, as noted above (see Kunar et al., 2006b), if set sizes are large enough and the time taken to respond to the display is long enough, then some guidance processes may come into play.

Other Factors in Contextual Cuing

Given that evidence for attentional guidance in contextual cuing is weak and that response selection seems to account for only a part of the contextual cuing effect, what other factors might be involved? One possibility is that contextual cuing helps in the initial processing of the display. That is, a predictive display may help one parse the stimuli from the background. Pilot work in our lab has shown that this might be the case. A greater RT benefit for predictive displays is found in complex displays, in which it is more difficult to separate the distractor and targets from the background, than in displays in which this segregation is easy. It seems that if the segregation between background and display is more difficult, a predictive context will help display parsing more, which in turn will lead to faster response times. It is up to future researchers to examine whether, together with weak guidance and facilitated response selection, these contributors can account for the contextual cuing effect in full. In the meantime, however, data from our experiments suggest that attentional guidance is not, by itself, an adequate account of contextual cuing.

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