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Contextual cost: When a visual-search target is not where it should be

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Abstract

Visual search is often facilitated when the search display occasionally repeats, revealing a contextual-cueing effect. According to the associative-learning account, contextual-cueing arises from associating the display configuration with the target location. However, recent findings emphasizing the importance of local context near the target have given rise to the possibility that low-level repetition priming may account for the contextual-cueing effect. This study distinguishes associative-learning from local repetition-priming by testing whether search is directed toward a target's expected location, even when the target is relocated. After participants searched for a T among Ls in displays that repeated 24 times, they completed a transfer session where the target was relocated locally to a previously blank location (Experiment 1) or to an adjacent distractor location (Experiment 2). Results revealed that contextual-cueing decreased as the target appeared farther away from its expected location, ultimately resulting in a *contextual cost* when the target swapped locations with a local distractor. We conclude that target predictability is a key factor in contextual-cueing.

Keywords

contextual-cueing; visual search; repetition priming

Introduction

Whether it is snatching a drink from the fridge or looking for keys in an office, visual search is often conducted within a familiar environment. Search speed is affected not only by perceptual characteristics of a display such as target saliency, but also by prior learning of the search environment (Chun & Jiang, 1998; Logan, 1988). Search is faster (though not always more efficient) when observers search in a previously encountered display than in a new display (Chun & Jiang, 1998), provided that the relative locations of the target and distractors have not changed since the display was last encountered (Oliva, Wolfe, & Arsenio, 2004; Wolfe, Klempen, & Dahlen, 2000). Such facilitation is known as contextual-cueing, as the repeated search display serves as a context that cues attention to the target location (Chun & Jiang, 1998).

Previous studies have shown that contextual-cueing can occur in multiple stages during search. Prior to the detection of the target, contextual memory of the repeated display can guide visual attention toward the associated target location, resulting in faster search speeds (Chun & Jiang, 1998; Johnson, Woodman, Braun, & Luck, 2007; Logan, 1988; Peterson & Kramer, 2001). Once the target is located, repeated displays can further speed up search by

reducing the double-checking and verification process for the target (Kunar, Flusberg, Horowitz, & Wolfe, 2007). At either stage of processing, the facilitation by repeated context depends on successfully matching the current search display with the previous memory (Logan, 1988; Song & Jiang, 2005).

The degree to which contextual-cueing can tolerate mismatches between the previously established memory and the current search display depends on how the mismatch is introduced. On the one hand, distortions to the distractor locations are well tolerated as long as the target's relative location in the configuration is preserved. For example, contextual-cueing is found when the search display is spatially shifted or resized (Jiang & Wagner, 2004), or when only a subset of distractor locations is repeated (Olson & Chun, 2002; Song & Jiang, 2005). On the other hand, contextual-cueing is eliminated when the target location is shuffled with distractor locations, even when the global configuration is preserved (Chun & Jiang, 1998; Oliva et al., 2004; Wolfe et al., 2000). However, previous studies have not systematically manipulated the displacement of a target's location from the previously learned target location, so they do not inform us about the precision of the target-related contextual memory. One goal of the present study is to examine the degree to which target relocation is tolerated in contextual-cueing. We achieve this goal by parametrically manipulating the distance between the current target location and a learned target location.

At the theoretical level, examining the impact of target relocation after successful contextual-cueing learning can shed light on the underlying mechanism of contextual-cueing. The dominant theory of contextual-cueing is the associative-learning account, according to which consistent associations between a repeated display configuration and the target location are established during learning (Chaumon, Drouet & Tallon-Baudry, 2008; Chun & Jiang, 1998). When the repeated display is encountered again, it serves as a predictive cue for the associated target location. The key support for the associative-learning account is the finding that shuffling target and distractor locations eliminates contextual-cueing (Chun & Jiang, 1998; Wolfe et al., 2000). There are, however, at least two accounts of the shuffling effect. On one account, shuffling target and distractor locations destroys the association between the global configuration and the target location. If contextual-cueing reflects associative learning, this manipulation would eliminate the benefit. On another account, moving the target to a distractor location changes the local context around the target, i.e., the new target and its adjacent distractor locations no longer match the old target and its adjacent distractor locations (Figure 1). If contextual-cueing depends on the repetition of locations adjacent to the target, then it should also be eliminated by the shuffling manipulation. Indeed, studies have shown that distractor locations near the target, such as those within the same quadrant, play a more important role in contextual-cueing than distractors farther away from the target (Brady & Chun, 2007; Olson & Chun, 2002). Changing the local context (as a consequence of shuffling) can therefore be detrimental. This analysis shows that the shuffling effect fails to distinguish the associative-learning account from a local repetition-priming account. The latter emphasizes the importance of repeating the spatial locations around the target location, but does not emphasize the necessity to maintain consistent associations between the search layout and the target's location.

Parametrically relocating the target from its learned location can provide additional tests for the associative-learning account. According to this account, when the current search display is sufficiently similar to previously encountered displays, it will engage the associative process, which directs search toward the predicted target location. Search can be quickly completed if the current target is at that location, but needs to restart from the predicted location when the current target is relocated. Therefore, on relocated trials, search RT is the sum of RT_{old} and RT_{additional-search}. The amount of time it takes to perform the

additional search is influenced by the distance between the expected target location (where attention is initially directed to) and the relocated target location (Downing, & Pinker, 1985; Egly & Homa, 1991). If this distance is short, this sum may be similar to RT_repeat; as the distance becomes greater, this sum may become similar to RT_new; at even greater distances, it can exceed RT_new, leading to a contextual cost. In short, the associative-learning account predicts a distance effect when targets are relocated, and can yield contextual facilitation, no enhancement, or contextual cost, depending partly on how far the target is relocated from its expected location.

Because consistent association between a context and the target location is not an element of the local repetition-priming account, this hypothesis makes somewhat different predictions about the consequence of target relocation. According to this account, the repeated context does not serve as a predicting factor that directs attention toward the target location. Instead, target localization proceeds in the same manner for repeated and unrepeated displays. However, the similarity between the local context surrounding the target and previously remembered local context provides priming for a speeded response. Relocating the target changes the local context. The farther the target is placed from the original location, the greater is the change and thus contextual-cueing should decrease with greater distance. As the distance further increases, the relocated display will no longer resemble the previously repeated displays in the local context surrounding the target, eliminating the benefit of repetition priming. Thus, the local repetition-priming account also predicts reduced or eliminated contextual-cueing as the target is relocated farther from the learned location. This account, however, does not predict a reversal of the contextual-cueing effect, as a relocated display will not be any more different from the learned display than a new display is.

We report two experiments that are designed to test the effect of relocating a target after successful contextual learning. Unlike previous experiments that relocate a target by shuffling it with distractors, our experiments parametrically manipulate the distance between the new target location and the learned location. Additionally and in contrast to past studies (e.g., Kunar, Michod, & Wolfe, 2005), relocation was implemented only after participants had been trained on a consistent target location, ensuring that strong contextual-cueing had already been established before the relocation manipulation. This design allows us to probe the precision of target-related contextual-memory, which in turn has implications for the associative-learning and the local repetition-priming accounts.

Experiment 1

The goal of the first experiment was to test the sensitivity of contextual-cueing to small changes in target positions. In this experiment we displaced the target by placing it at a previously blank location near the original target location. During training, observers were exposed to several search displays that occasionally repeated. Each time a particular display was presented, both the target and distractors were in their original positions. Afterwards and unknown to the participants, the original search displays were changed by relocating the target to a previously empty location “1-step” (approximately 2.16°) or “2-steps” (approximately 4.32°) away from its original location. Following Kunar et al., (2007) we also varied the number of distractors on the display to test whether learning would affect search slope in addition to its effect on overall speed.

Method

Participants—Participants in this study were students from the University of Minnesota and Harvard University with normal or corrected-to-normal visual acuity. Twenty-eight participants (ages 18-30 years) completed Experiment 1.

Equipment—Participants were tested individually in a normally lit room and sat unrestricted at about 57cm from a 19" monitor. The experiment was programmed with the psychophysics toolbox (Brainard, 1997; Pelli, 1997) implemented in MATLAB (www.mathworks.com).

Materials—Participants searched for a T (1.44°) rotated to the left or right among L-shaped distractors rotated in the four cardinal directions (the offset at the junction of the two segments was 5 pixels). The items were white and presented on a gray background. Each item was positioned on a different arm of an imaginary spider-web grid. The spider-web was constructed of 6, 8 or 10 equidistant arms and five circles at eccentricities of 3.6° , 5.76° , 7.92° , 10.08° and 12.24° .

Procedure—Each trial began with a fixation point (0.22°) for 400msec followed by 400msec of a blank interval. The search display was then presented until participants pressed a key to indicate the direction of the T's tip. The target's orientation was evenly and randomly divided between left and right within each block. Participants were instructed to respond as accurately and as quickly as possible. Auditory feedback was given on incorrect responses.

Design—In the *training* phase, participants completed 24 blocks, each consisted of 30 trials. The 30 trials were unique visual displays, randomly and evenly divided into three set sizes: there were 6, 8, or 10 items on the display, each occupying a different "arm" on the imaginary spider web. These displays were repeated once per block for 24 times. Each of the trained displays was later tested in four conditions during the *transfer* phase (Figure 2). In the *old*-condition, both the target and distractors kept their locations. In the *1-step-relocation*- condition distractors' locations were maintained but the target was move one step (2.16°) along its arm. In the *2-step-relocation*- condition the target moved two steps (4.32°) along its arm. The direction of the movement was equally likely to be inward or outward in both conditions, which ensured that target eccentricity was on average equivalent across all conditions. In the *new*- condition the target kept its position, yet all distractors randomly changed their positions along their arms. All four conditions were inter-mixed within a block and participants performed 3 blocks of the *transfer* phase (total of 360 trials).

Results

Accuracy—In both the *training* and *transfer* phases of the experiment accuracy was over 97%. It was not significantly influenced by *transfer* conditions, $F(3, 81) < 1$. In the reaction time (RT) analysis, we excluded incorrect trials as well as trials exceeding three standard deviations above and below each participant's mean of each condition.

Training phase—Figure 3A depicts the mean RT of the training phase as a function of training block and set-size. A repeated-measures ANOVA on these two factors revealed significant effects of set-size, $F(2, 52) = 93.46$, $p < .01$, block, $F(23, 598) = 20.46$, $p < .01$, and their interaction, $F(46, 1196) = 2.73$, $p < .01$. The interaction showed that participants improved more at set size 10 than at the other two set sizes (see also Kunar et al., 2005), especially in the first few blocks of trials. Because we did not include new displays in the training phase, we could not differentiate general procedural learning from contextual-learning in these data.

Transfer phase—Figure 3B shows the *transfer phase* results as a function of set-size and transfer condition. A repeated-measures ANOVA on set-size (6, 8, 10) and condition (old, 1-step-relocation, 2-step-relocation, new) found main effects of set-size, $F(2, 54) = 90.94$, $p < .01$, and transfer condition, $F(3, 81) = 6.7$, $p < .01$, but no interaction, $F < 1$. Follow-up tests

showed that RT was comparable for *old* trials and *1-step-relocation* trials ($p=.41$), and comparable for *new* trials and *2-step-relocation* trials ($p=.37$). The *old* and *1-step-relocation* conditions were both faster than the *new* ($p's<.01$) and *2-step-relocation* ($p's<.05$) conditions.

Discussion

Experiment 1 tested the sensitivity of contextual-cueing to changes in target position. After participants were trained on a set of visual search displays that repeated 24 times in their entirety, they were tested on displays where the target relocated to a blank location near the original target location. The displacement was either 1-step (2.16°) or 2-steps (4.32°) away from the original target location, both of which could be considered as local displacement (Brady & Chun, 2007). Results revealed a distance effect in contextual-cueing: contextual-cueing was preserved when targets were relocated 2.16° from their trained location, but eliminated when targets were relocated 4.32° from their expected location. These results suggest that although target-related contextual-memory is not hyper-precise (contrary to earlier findings using eye movement measures, see Peterson & Kramer, 2001), its tolerance for displacement is limited. Finally, similar to past reports (Kunar et al., 2007), the contextual-cueing or target relocation effects did not interact with set-size, showing no clear effects on search efficiency. We return to this issue after Experiment 2.

The distance effect observed in the relocation manipulation of Experiment 1 provides an important empirical characterization of the precision of target-related contextual memory. At the theoretical level, however, it is consistent with both the associative-learning account and the local repetition-priming account, both of which predict a reduction in contextual-benefit as the target is relocated farther away from the trained location. An empirical test for these two theories would come from studies where the target is further relocated beyond the distances used in Experiment 1. At a greater distance, contextual-cueing benefit may reverse to a contextual-cost according to the associative-learning account, but it will simply be eliminated according to the local repetition-priming account. Experiment 2 attempts to distinguish these two possibilities by using greater target displacement.

Experiment 2

Experiment 2 was similar in design to Experiment 1. But instead of moving the target into a new empty location during the transfer phase, the target swapped locations with a nearby distractor. Unlike previous studies in which the target freely roamed locations in repeated configurations, we constrained the location of the target to locations previously occupied by distractors that were either relatively near (1-step-swap) or far (2-step-swap) from the original target location. Computer simulation showed that the averaged distance in the 1-step-swap condition was 5.2° ($SD=0.2^\circ$), which was slightly greater than the 2-step relocation condition of Experiment 1 (4.32°). The average distance in the 2-step-swap condition was 8.2° ($SD=0.3^\circ$), a significantly greater distance than the 1-step-swap, $p<.00001$. Similar to Experiment 1, we expect to find a distance effect in that RT should be slower in the 2-step-swap than the 1-step-swap condition. Of interest is whether the greater displacement used in the 2-step-swap condition could result in a contextual-cost – slower RT in that condition than the baseline (*new*) condition.

Method

Participants—Twenty-five participants (age 18-35 years) completed Experiment 2.

Design—The experimental stimuli and design were identical to those used in Experiment 1 except for the following changes: White items (1.08°) were presented on a black

background. The spider-web grid was composed of 8, 12 or 16 total arms with five possible eccentricities (3.6°, 5.4°, 7.2°, 9.0°, 10.8°). There were 8, 12, or 16 items on each display, each occupying a different arm. Four critical conditions were tested in the *transfer* phase (Figure 4). As in experiment 1, the *old* condition preserved the locations of the target and distractors and a *new* condition presented the target in its original location while randomly changing the arm position of the distractors. In the *1-step-swap- condition* the target switched locations with one of the adjacent (one-arm away) distractors. In the *2-step-swap- condition* the target switched locations with a distractor two arms away.

Results

Accuracy—Similar to Experiment 1, accuracy in the training and transfer phases of the experiment was over 97%. It was not significantly affected by the *transfer* conditions, $F(3, 72)=1.54, p=.21$. Incorrect trials and trials in which response times exceeded three standard deviations above and below each participant's mean of each condition were excluded from the RT analysis.

Training phase—Figure 5A shows the mean RT of the training phase as a function of block and set-size. A repeated-measures ANOVA found significant effects of set-size, $F(2, 48)=181.44, p<.001$, block, $F(23, 552)=17.20, p<.01$, and their interaction, $F(46, 1104) = 2.46, p < .01$. Just like Experiment 1, the slope reduction (as indicated by set size $\times$ block interaction) was evident only in the first third of the experiment. The interaction was insignificant after that ($p>.10$).

Transfer phase—Figure 5B shows the results of the *transfer phase* as a function of set-size and transfer condition. An ANOVA on set-size (8, 12, 16) and condition (old, 1-step-swap, 2-step-swap, new) revealed main effects of set-size, $F(2, 48)=311.36, p<.01$, and condition, $F(3, 72)=7.03, p<.01$, but no interaction, $F<1$. Thus, similar to Experiment 1 we found no evidence for reduced search slope as a result of contextual-learning.

Follow-up tests showed that *old* trials were faster than all of the other conditions (all p 's<.05). No contextual facilitation was found in the *1-step-swap* condition compared to the *new* condition, $F<1$. Importantly, the *2-step-swap* condition was slower than both the *1-step-swap*, $F(1, 24)=4.35, p<.05$ and the *new* conditions, $F(1, 24)=6.09, p<.05$, revealing a contextual cost.

Discussion

Experiment 2 replicated the distance effect seen in Experiment 1, where search RT on target-relocated displays became longer as the target became further displaced from its trained location. In addition, this experiment also revealed a contextual-cost for a target that swapped locations with a distractor 2-steps away (about 8.2°). To our knowledge, this is the first demonstration that memory for a search display can impair one's search performance. Would performance be further delayed if the target appears even farther away? This is possible, but the contextual cost should eventually saturate at farther distances.

Contextual cost was not observed in a previous study that randomly shuffled target and distractor locations (Chun & Jiang, 1998), possibly because the original contextual-learning was weaker in that study than in our. In the Chun & Jiang's study, the repeated search display was predictive of two possible targets instead of one, reducing the likelihood that a contextual cost would be observed.

General Discussion

This study examined the precision of target-relocated contextual memory in visual search. Two experiments revealed a distance effect after the target was relocated away from its expected location. Contextual-cueing facilitation was reduced when the target appeared farther away from its learned location and the effect was ultimately reversed when a target switched locations with a far distractor (Experiment 2). Although both the associative-learning and the local repetition-priming accounts can explain the distance effect, the contextual cost effect is not easily accommodated by the local repetition-priming account, as a relocated display cannot be any more dissimilar to the learned display than a new display is. Thus, the finding of contextual cost effect highlights the importance of target's predictability in contextual-cueing and further suggests that at least part of the contextual-cueing benefit occurs before the detection of the target. Together, these findings provide strong support for the view that contextual-cueing is a form of top-down associative-learning.

In our discussion thus far, we have attributed the difference between Experiments 1 and 2 primarily to a distance effect. The target was relocated to a smaller degree in Experiment 1, where a 2.16° relocation did not disturb contextual-cueing yet a 4.32° relocation eliminated it. In Experiment 2, a 5.2° relocation eliminated contextual-cueing and an 8.2° relocation produced a contextual-cost. A distance effect can account for differences within each experiment as well as differences between experiments. However, the two experiments also differed in another important aspect: the target was relocated to an empty location in Experiment 1 and to a previous distractor location in Experiment 2. Thus, the between-experiment difference may be partly attributed to the presence of distractor-inhibition (Ogawa, Takeda, & Kumada, 2007). Can the inhibition account also explain the within-experiment distance effect? We think that it cannot, as previous studies have shown that distractors closer to the target are often inhibited more strongly than distractors farther away from the target (e.g., Muller, Mollenhauer, Rosler, & Kleinschmidt, 2005). The inhibition account also seems a weak explanation between experiments. Because similar relocation-distance was used for the *2-step* relocation condition of Experiment 1 and the *1-step-swap* condition of Experiment 2, a simple distance effect would predict similar results from these two conditions, and this was confirmed by our data. However, the inhibition account would predict a cost for the *1-step-swap* condition, which was not observed. It is important to note, however, that the inhibition-hypothesis is also associative in nature, as it proposes that the learned configuration is not only predictive of the learned target, but also predictive of which locations do not contain the target. Future studies are needed to evaluate the separate role of distractor inhibition and the target-relocation distance effect in contextual-cueing.

An important finding in contextual-cueing is that repeated exposure to a search display rarely affects search slope (Kunar et al., 2007; Kunar, Flusberg & Wolfe, 2008). In line with these findings, we failed to find any evidence that memory effects were greater at larger set sizes. At first glance, this result apparently presents a challenge to the associative-learning account, as the addition of memory-guided search may be particularly useful when regular perceptual-based search takes longer. However, unlike featural attentional guidance (Wolfe, 1994), in order for memory to guide attention, the spatial configuration must first be recognized. The recognition process is not perfect, however, as several studies have shown that memory benefit is not revealed on every trial, or at the beginning of a trial (Johnson et al., 2007; Peterson & Kramer, 2001). Together with the assumption that it is more difficult to recognize a subset of items among larger displays, one might expect that fewer trials would reveal guidance effects with increased set-size. This in turn would cancel out any guidance effects reflected by shallower search slopes. Therefore, the lack of a difference in

search slopes may not be taken as evidence against the presence of attentional guidance based on associative-learning.

Conclusion

By relocating the search target parametrically to a new location, this study provides important empirical data that characterizes the precision of target-related contextual memory. It shows that there is a limited tolerance for target relocation in contextual-cueing. As the target is relocated at greater distances from expected locations, the benefit from a repeated display can be eliminated or reversed into a contextual cost. These results underscore the importance of target's predictability in contextual-cueing and argue against low-level local repetition accounts of memory-based effects in visual search.

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Figure 1.

A schematic illustration of shuffling a target's location while maintaining the locations of all items. Note that the local context surrounding the target is different in the two trials.

Figure 2. Schematic displays of the four transfer conditions tested in Experiment 1 (the circle and the grid were not visible for the participants).

Figure 3.
Training and Transfer results of Experiment 1.

Figure 4.
Schematic displays of the four transfer conditions tested in Experiment 2.

Figure 5.
Training and Transfer results of Experiment 2.