Interaction Between Object Cueing and Spatial Cueing in Visual Search

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To conduct an efficient visual search, visual attention must be guided to the target appropriately. Previous studies have suggested that attention can be quickly guided to a target, when the spatial configurations of search objects, or the object identities have been repeated. This phenomenon is termed “contextual cueing”. In this study, we investigated the effect of learning spatial configurations, distractor identities, and a combination of both configurations and identities, on visual search. The results show that visual search is more efficient when searching for repeated stimuli than when searching for new ones (i.e., configuration-repetition, identity-repetition, or a combination of them). Furthermore, learning was superior when configuration and identity were repeated than in the other two repetition conditions. These results suggest that the effects of contextual cues are associated with both configuration and identity learning, and that the effects of these two types of contextual cueing are additive. These findings are consistent with the hypothesis that contextual cueing operate through two functionally independent learning mechanisms.

Keywords: contextual cueing, spatial configuration, object identity.

Introduction

Many studies have demonstrated that a target defined by salient visual features such as color or orientation can be located faster and more constantly, independent of set size. This is referred to as “parallel” or “efficient” search (Treisman & Gelade, 1980; Wolfe, 1994). Unlike the search for a salient target, natural scenes do not necessarily contain salient, bottom-up information. Often, they contain too much information to guide attention efficiently (Chun, 2000). Visual context plays an important role in scene perception. A target appearing in a particular scene can be detected more quickly with repeated learning of the scene. Chun and Jiang (1998) examined context-learning effects in visual search. They demonstrated that the search for a repeatedly presented configuration is faster than for a newly generated configuration. This facilitation effect is termed “contextual cueing”.

Contextual cueing is the guidance of attention based on the implicit memory of an association between a global context (i.e., a spatial configuration) and a target location (Chun & Nakayama, 2000). This effect can be observed despite chance performance for recognizing the learned configurations, suggesting that the memory for context information is implicit. Moreover, it has been suggested that the complete spatial configuration is unnecessary for spatial cueing to be effective. Spatial cueing depends on locally grouped distractors, or an attended set of distractors associated with the target location (Jiang & Chun, 2001; Olson & Chun, 2002).

Visual context also involves other attributes such as object identities (Biederman, Mezzanotte, & Rabinowitz, 1982). Chun and Jiang (1999) examined whether the context, based on object identities, guided visual attention to the target. In their study, the pairing between the location of a target and the configuration of distractors was randomized in every trial, but the pairing of identities between target and distractor sets was kept constant using novel contour shapes. They found that significant object cueing effects, similar to spatial configuration cueing, occurred in this condition. This indicates that visual attention could be guided to a target, as far as the context maintained the association between the target and distractor identities.

It has been suggested that learning both the spatial configuration and object identities could guide attention to a target. However, it is unclear whether contextual cueing occur independently, because spatial cueing and object cueing have been investigated in separate studies. In this study, we examined the interaction between spatial cueing and object cueing in the visual search.

We manipulated both the spatial configuration and object identities by using three repetition conditions; spatial configuration repetition, object identity repetition, and the same combination of both repetition conditions (combined-repetition condition). To examine the contextual cueing effect, these three repetition conditions were compared with a control condition, in which new spatial configurations and new object combinations were generated. If each type of contextual cue is associated with separate mechanisms, then there should be an additive effect of spatial and object cueing, when both the spatial configuration and object identities were repeated. Thus, the hypothesis of separate mechanisms for spatial and object cueing predicts that the effect of contextual cueing in the combined-repetition condition would be equal to the sum of the effects of spatial configuration repetition and object identity repetition conditions. On the other hand, no such additive effect would be observed if each type of contextual cueing is observed if each type of contextual cueing is based on identical mechanism.

Method

Participants

Nineteen observers participated in this experiment as paid volunteers. All observers had normal or corrected-to-normal visual acuity. None of the observers was aware of the purpose of the study.

Apparatus

All stimuli were displayed on a 17-inch color monitor (SONY Multiscan 17SF9) connected to a personal computer (EPSON Type-HS). A program written in MATLAB (The Mathworks, Inc) controlled the schedule of the experiment. Responses were collected by using a mouse and a numeric keypad, and reaction times and accuracy were recorded on the computer. Observers sat in front of the display monitor at a viewing distance of approximately 57cm.

Stimuli

In this experiment, we used a total of 91 novel contour shapes (see Figure 1). All shapes were illustrated by hand (Endo, Saiki, Nakao, & Saito, 2002). Each shape subtended an approximate visual angle of 2.5º x 2.5º. A target, which was defined as a closed contour, and nine distractors, which were defined as open contours (with a gap of approximately 0.2º of visual angle) were used as search stimuli. The target and distractors were positioned in 10 randomly selected locations of an invisible 6 x 6 matrix, which subtended a visual angle of 21º x 21º. The contours were white, and the background was gray.

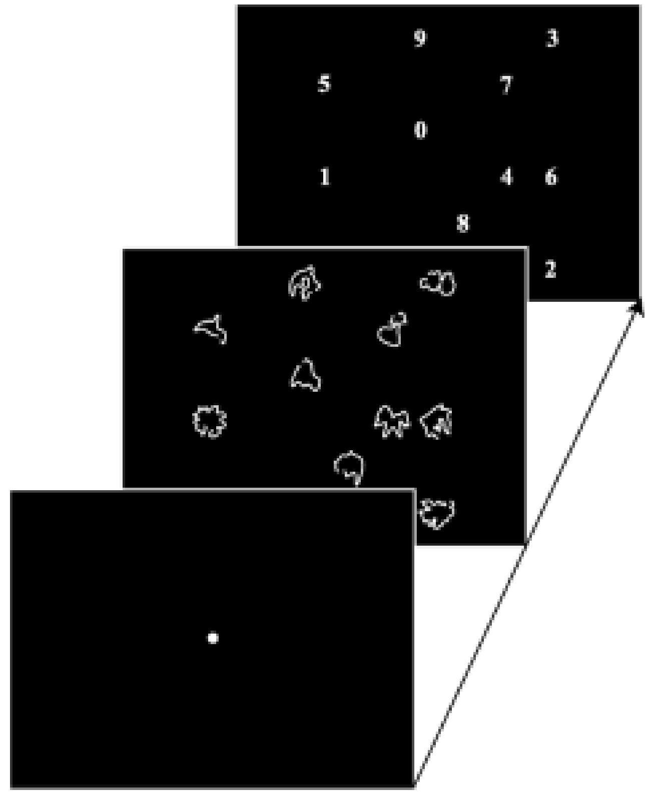

Figure 1. A sample of the stimuli used in this experiment.

Design

A 5 x 4 within-subject design was utilized with the epoch as Factor 1. An epoch consisted of 5 blocks, with a block containing 28 trials. Factor 2 was repetition, consisting of four conditions: *old*, *identity-old*, *configuration-old*, and *new*. Each condition consisted of seven randomly generated configurations and combinations of object identities, which appeared once per block. A set of configurations and identities for each condition was generated separately for each observer and they were presented as follows. In the old condition, the same seven sets were repeatedly presented throughout the experimental session (25 times, 5 epochs x 5 blocks). In the identity-old condition, the combination of target and distractor identities was constant, but distractor locations were randomly changed from block to block. In the configuration-old condition, the locations of target and distractors were repeated, while distractor identities were changed from block to block. Finally, in the new condition, both distractor identities and their locations were randomly chosen in each block to provide the baseline measure. Hence, any difference in performance between the new condition and the other three conditions could be attributed to learning of the context based on object identities and/or spatial configurations.

Procedure

Each trial began with the presentation of a white fixation dot at the center of the display. After 1000 ms from the onset of the fixation, a search stimulus appeared. Participants were required to search for the target (i.e., the closed contour) and respond as quickly as possible by pressing the mouse button. Immediately after a response, the search stimulus disappeared and the target localization display was presented (see Figure 1). To confirm the accuracy of the visual search performance, participants were required to press one of the keys corresponding to the digit positioned in the target location. After this, the display was cleared, and the next trial followed 2s later. If the target localization were incorrect, a beep sounded as feedback. Before the experimental session, each participant practiced for 56 trials using targets and distractors, as well as a spatial configuration that was different from those used in the experimental session. The experiment lasted for approximately 1 hour.

Results

All trials with target localization errors, as well as trials with target search reaction times (RTs) longer than 6000ms (outliers), were excluded from the data analysis. Data of three observers were excluded from the analysis due to the excluded trials above 10%. The mean correct RTs are shown in Figure 2. To examine the effect of contextual cueing, RTs were subjected to a two-way analysis of variance (ANOVA) with epochs (1-5 epochs) and repetition conditions (old, identity-old, configuration-old, and new) as the main terms. The ANOVA indicated that the main effect of epoch was significant, F (4,60)=45.64, p<.0001, suggesting that the observer's response speeds increased as the experiment progressed. Moreover, there was a significant interaction between epoch and the repetition condition, F (12,180)=1.86, p<.043. This interaction is noteworthy, because we were mainly interested in the effect of context, based on spatial configuration, object identities, or both, on the efficiency of guiding visual attention to a target. As shown in Figure 2, in Epoch 5, RTs were extremely faster in the three repeated conditions than in the new condition, whereas in Epoch 1, this was not the case.

To examine differences in RTs between the new and the three remaining repeated conditions, a comparison of each repeated condition with the new condition was undertaken

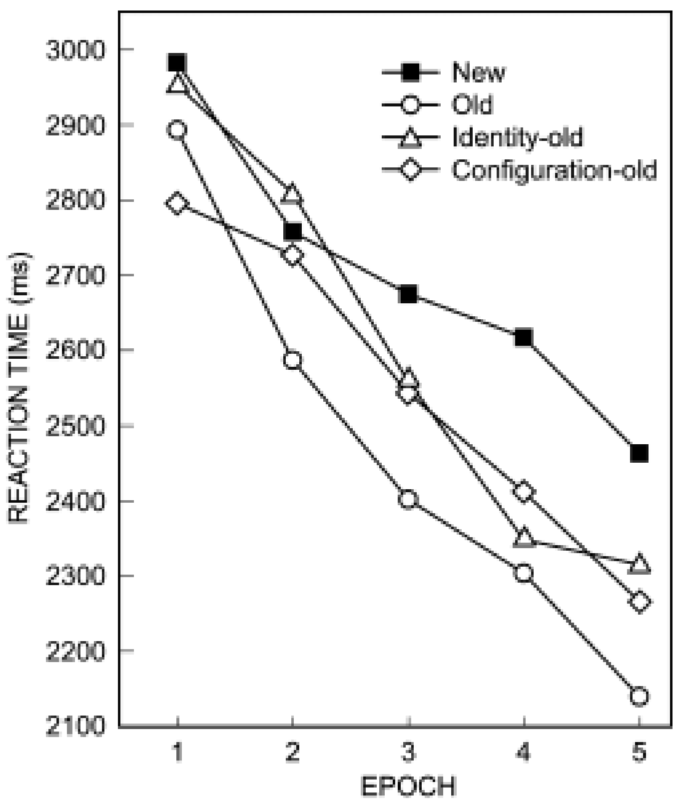

Figure 2. Reaction times as a function of epoch for each condition illustrate the learning function.

Table 1. Mean error rates as a function of repetition and epoch.

	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Epoch 5
Old	4.46	1.07	2.32	2.32	1.43
Config-old	2.32	2.50	1.43	1.96	0.71
Identity-old	3.39	1.96	2.32	2.14	2.14
New	3.75	1.79	2.32	1.96	1.79

using the Newman-Keuls test. This analysis revealed that there was a significant effect of cueing (i.e., a significant difference in RTs between the new condition and each repeated condition) in Epoch 3, in the old condition (M=273ms, p<.002), and this advantage was maintained over time (Epoch 4: M=314ms, p<.0002; Epoch 5: M=324ms, p<.0001). In the configuration-old condition, the cueing effect was significant in Epoch 4 (M=205ms, p<.035) and marginally significant in Epoch 5 (M=197ms, p<.066). In the identity-old condition, the cueing effect was significant in Epoch 4 (M=269ms, p<.003), although it failed to reach significance in Epoch 5.

In this study, RTs in the old condition were always faster than in the other two repeated conditions, with the exception of Epoch 1. In Epoch 5, the difference in RTs between the old condition and the configuration-old condition was significant (M=175ms, p<.050), and that between the old condition and the identity-old condition was marginally significant (M=127ms, p<.066).

Mean error rates as a function of epoch and the condition are shown in Table 1. Mean error rates were subjected to a two-way ANOVA with epochs and repetition conditions as the main terms. The main effect of epoch was significant, F(4,60)=6.39, p<.0002, showing more errors in Epoch 1 than in subsequent epochs (all ps<.005). The main effect of the repetition condition and the interaction were not significant, indicating that there was no speed-accuracy trade-off.

Discussion

In this study, we demonstrated contextual cueing effects based on both spatial configuration and object identities. The results are consistent with the findings of previous studies (Chun & Jiang, 1998, 1999). Chun and Jiang (1998) have proposed that attentional guidance in spatial cueing is based on implicit memory of the association between a distractor configuration and a target location, and that in visual search memory traces of target locations appropriately guide attention. On the other hand, object cueing is considered to be associated with the learning of the covariation between target identities and distractor identities, and that top-down expectancies regarding target identities facilitate visual search performance (Chun & Jiang, 1999).

The results of this study demonstrated that both spatial and object cueing effects can be observed in the same sequences, although in each trial, the participants were unaware of the relevant cue (i.e., configuration, identities, or both of them). This implies that an attentional set for locations or for identities is not necessary for each type of contextual cueing.

In this study, we observed faster RTs in the old condition, when both configuration and identities were repeated, relative to the other two repetition conditions. Furthermore, in the old condition, a stable contextual cueing effect was observed from Epoch 3 to 5, whereas the configuration-old condition and the identity-old condition yield significant contextual cueing effects in only Epoch 4. This indicates that contextual cueing in the old condition resulted from the sum of spatial cueing effects and object cueing effects. Overall, the findings of this study are consistent with the hypothesis that contextual cueing operates over two functionally independent learning mechanisms (i.e., spatial configuration learning and object identity learning).

Conclusion

The purpose of this study was to clarify the role of context learning in visual search, and to examine the interaction of the effect of cueing in different types of contexts. The results suggest that the visual system is capable of learning repeated attributes, such as spatial configurations and object identities, without an attentional set. These learned contexts could be used as cues for attentional guidance in visual search, even if different types of contexts are used within a sequence. More interestingly, when the context was defined by both spatial configurations and object identities, the effects of the two types of contextual cueing were additive, suggesting that each type of contextual cueing is based on separate mechanisms.

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