Vision Research 107 (2015) 76–85

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The location but not the attributes of visual cues are automatically encoded into working memory

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ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 14 November 2014
Available online 6 December 2014

Keywords:
Visual cueing
Object files
Attention
Visual working memory

ABSTRACT

Although it has been well known that visual cues affect the perception of subsequent visual stimuli, relatively little is known about how the cues themselves are processed. The present study attempted to characterize the processing of a visual cue by investigating what information about the cue is stored in terms of both location ("where" is the cue) and attributes ("what" are the attributes of the cue). In 11 experiments subjects performed several trials of reporting a target letter and then answered an unexpected question about the cue (e.g., the location, color, or identity of the cue). This surprise question revealed that participants could report the location of the cue even when the cue never indicated the target location and they were explicitly told to ignore it. Furthermore, the memory trace of this location information endured during encoding of the subsequent target. In contrast to location, attributes of the cue (e.g., color) were poorly reported, even for attributes that were used by subjects to perform the task. These results shed new light on the mechanisms underlying cueing effects and suggest also that the visual system may create empty object files in response to visual cues.

1. Introduction

A primary goal of visual cognition is to understand how attentional filters are affected by visual cues. In this context, the term visual cue typically refers to a visual stimulus that appears in the periphery. These cues alter the prioritization of certain stimuli according to their spatial location, such that processing is enhanced at the cued location and is diminished at other locations. This enhancement produces improvements in discrimination accuracy, reaction time, and even changes in perceived appearance (Carrasco, Ling, & Read, 2004; Posner, 1980; Posner, Snyder, & Davidson, 1980; Shiu & Pashler, 1994). Furthermore, a cue will cause reductions in accuracy and increases in reaction time for discrimination and detection of stimuli outside of the cued region (Cheal & Lyon, 1989).

While it has been well established that visual cues cause rapid and dramatic changes in the attentional filters employed by the visual system, relatively little is known about how the cues themselves are processed. For example, one issue that has received little inquiry is the degree to which the cue itself is encoded into memory when subjects do not expect that they will need to remember it. The answer to this question has important implications for our understanding of how attention and memory encoding interact. For example, in the case of the attentional blink, there are limitations in the rate of memory encoding that are either inherent in the visual system (Dux & Marois, 2009), or the result of strategic suppression of attention by memory encoding (Bowman & Wyble, 2007; Wyble, Bowman, & Nieuwenstein, 2009; Wyble, Potter, Bowman, & Nieuwenstein, 2011). Specifically, encoding of the first target (T1) in an attentional blink paradigm reduces the ability to encode and report the following target (T2).

These dynamics may also play a role in spatial cueing effects such that encoding of the cue itself may alter the ability to encode the following target. In other words, the observed effect of a cue on a following target may reflect a composition of multiple factors, including both the attention recruited by the cue as well as any costs incurred by encoding the cue into working memory (WM). Therefore, to clarify how the cues themselves are processed (e.g., encoded and maintained in the WM) is of great importance for us to fully understand the mechanisms underlying various cueing effects.

To examine this question, the present study attempted to characterize the processing of the cue by investigating whether memory traces of the location ("where" is the cue) and attributes[1] of the

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[1] The attribute refers to an aspect of a stimulus (e.g., color, identity, etc) as suggested by Kanwisher and Driver (1992).

http://dx.doi.org/10.1016/j.visres.2014.11.010
0042-6989/

cue ("what" are the attributes of the cue) are automatically formed[2]. This question has not yet been addressed because, while it has been easy to study the effect of cues on subsequent targets, it is much more difficult to study how the cues themselves are encoded into WM. This is because asking participants to report the cues would cause a participant to treat them as targets on subsequent trials.

To address this problem, we adopt a paradigm similar to that used by inattentional blindness studies (e.g., Mack & Rock, 1998; Rock, Linnett, Grant, & Mack, 1992), although there are several critical differences. In a typical inattentional blindness study, participants were asked to focus their attention on one task and then they were asked to report the information about an unexpected stimulus in a surprise trial. The result usually shows that participants rarely report the unexpected stimulus, and such a failure of report was traditionally attributed to a lack of attention on the unreportable stimulus.

However, it remains unknown whether people can report the location or attributes of an expected cue that triggers attention, but that they have no expectation of reporting. To answer this question, participants in our paradigm perform several trials of a cueing experiment in which they report a target letter without reporting the preceding visual cue, and then answer a surprise question about the cue (e.g., its location or color). After this point, the participant's attentional set is considered to be contaminated by the expectation that they should try to encode the cue and the subject is then ineligible to participate in further experiments regarding this topic.

2. Experiment 1

In the first experiment we investigated whether the location of the cue is automatically encoded into WM. We examined this issue by asking participants to report only the target letter appearing after the cue in a series of trials and then asking them to report the location of the cue in a surprise question on the last trial.

2.1. Method

Participants: Eighteen Pennsylvania State University undergraduates (all reported normal or corrected-to-normal visual acuity) participated in this experiment in exchange for credit for a course requirement. For this and all following experiments, no subjects were excluded after data collection, and all of the measures that were recorded from subjects are reported. Before beginning the experiment, all subjects read and signed a consent form approved by our institution's IRB. All of the experiments reported here were conducted in accord with the Code of Ethics of the World Medical Association (Declaration of Helsinki). The data from all experiments described in this manuscript are located in ScholarSphere repository of the Pennsylvania State University at this URL: https://scholarsphere.psu.edu/collections/5712mc169.

Apparatus: Stimuli were presented on a 17-in CRT monitor with a resolution of 1024 × 768 pixels. Participants were seated approximately 50 cm away from the screen and entered responses via a computer keyboard. The animations were generated by using Matlab with Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) on a Windows XP operating system.

Stimuli: Four black placeholder circles (0.62°) were displayed on the four corners of an invisible square (6.25° × 6.25°), and the black central fixation cross (0.62°) appeared in the center of the invisible square. The cue consisted of two red rectangle bars (0.15° × 0.92°), with each one 0.63° above and below the placeholder. The targets were fifteen 0.86° × 0.62° black English letters (A, B, C, D, F, H, J, K, L, N, P, R, T, V, X) presented in the Arial font. All the stimuli were presented on a gray background (RGB: 150/150/150). The mask was generated by using two overlapped black symbols (@ and #).

Procedure and design: As shown in Fig. 1, each trial began with the fixation cross and four placeholders. After a variable duration (900–1900 ms), a cue appeared at one of four possible locations (defined by the four placeholders) for 80 ms. Before the experiment, participants were instructed that "You will also see some red bars flash on the screen before the letter. Sometimes the bars will indicate where the letter will appear". There were 12 trials in this experiment. On the first 11 trials, the cue was followed by a target in either the same location (valid condition, 50% of trials) or a different location (invalid condition, 50% of trials). The SOA between the cue and target was 100 ms and the target was masked 67 ms later and the mask duration was 100 ms. After a 400 ms blank screen, participants were asked to report the target letter. However, the final trial was a surprise trial, in which only the cue was displayed. After a 567 ms blank screen following the disappearance of the cue, participants were asked to report the location of the cue in a surprise question by choosing one of the numbers 1, 2, 3 or 4 which appeared at the same locations as the four placeholders on the screen. The whole experiment lasted about 2 mins.

2.2. Results and discussion

First 11 trials, target report accuracy: The accuracy in the valid condition was significantly higher than that in the invalid condition (0.643 vs. 0.113; paired $t(17) = 9.719$, $p < .001$), indicating that the cue was highly effective.

Surprise trial, cue location accuracy: 16 of 18 participants were correct in the surprise report of the cue location (probability: 16/18 = 0.89). A binomial test showed that the probability of correct report of the cue location was much higher than random guessing (probability of chance is 0.25; $p < .001$), indicating that the location of the cue was encoded into WM, despite the fact that subjects had not previously been asked to report the location. Note that there could not have been a motion artifact (e.g., apparent motion between the cue and target) to provide an indication of cue location, since there was no target after the cue on the surprise trial.

3. Experiment 2

As the cue was the most recently presented stimulus in the surprise trial of Experiment 1, it might be argued that participants were able to infer the location of the cue by sensing the distribution of their own covert attention, or by relying on the iconic memory of the cue (Di Lollo, 1977; Neisser, 1967), rather than encoding the location into WM. Therefore, Experiment 2 examined these possibilities by displaying a target letter after the cue in the surprise trial as well as in all other trials.

3.1. Method

This experiment was identical to Experiment 1 with the following exceptions. A new group of 20 undergraduates participated in this experiment. A target letter appeared after the cue in the surprise trial and it was not followed by a mask. On this surprise trial, participants were asked after target presentation to report first the location of the cue, and were then asked to report the target letter. For half of the participants, the target was displayed at the same location as the cue in the surprise trial (valid group). For the remaining participants, the target was presented on a different location in the surprise trial (invalid group) (Fig. 2).

[2] Our use of the word automatic refers to the fact that the information of cue was encoded into working memory despite the fact that it was not required to be reported by subjects on previous trials.