Vision Research 115 (2015) 92–103

Contents lists available at ScienceDirect

Vision Research

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

Singleton search is guided by knowledge of the target, but maybe it shouldn't be

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ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form 22 August 2015
Accepted 26 August 2015
Available online 3 September 2015

Keywords:
Singleton search
Current goals
Top-down
Inter-trial priming
Symbolic cues

ABSTRACT

Among studies of visual search for a singleton, some studies show evidence of top-down attentional guidance driven by goals, while others do not, leading to uncertainty as to how goal-driven guidance should be included in attentional theories. Six experiments tested this guidance when a target shape is found by locating a singleton feature (color or shape) and an orientation within the target is then reported. Experiments 1 and 2 use the dimensional priming paradigm underlying the most effective arguments against goal-driven guidance, and show evidence for guidance in many circumstances. Experiment 3 extends the results to feature priming, and demonstrates a complex interaction between attentional goals and memory for previous targets. In Experiment 4, symbolic (word) cues were just as effective as image cues, further strengthening the case for goal-driven guidance. In Experiments 5 and 6, as in the previous experiments, valid cues again produced faster responses than invalid cues, showing the advantage of goal-driven guidance. Surprisingly, however, responses were even faster when the cues were uninformative. Furthermore, participants who began the experiment with neutral cues seemed to ignore informative cues later in the experiment. The results show that attention can be guided by goals even in easy searches, but that searchers have much flexibility in the use of this guidance, and may choose not to use it. Furthermore, their decisions about using this guidance are not always well informed, because they are not aware of the relative costs and benefits.

1. Introduction

Many visual searches are difficult without foreknowledge of the appearance of the possible targets, and the properties that differentiate them from the distractors. Some targets, however, differ so markedly from their surroundings that their salience makes them easy to find. In the endeavor to understand how different attentional mechanisms contribute to visual search, some very helpful insights have emerged from studies that have asked whether the foreknowledge that helps in difficult searches also contributes to these easy "pop-out" searches.

In one of the early studies in this area, Bravo and Nakayama (1992) showed that even though a color singleton target was found quickly, it was found even more quickly when the colors of the target and distractors were constant across trials. The initial interpretation was that certainty about the target feature led to more effective attentional guidance. In a later study, Wolfe, Butcher, Lee, and Hyle (2003) combined manipulation of target feature certainty with manipulation of target dimension uncertainty (following up on studies such as Müller, Heller, & Ziegler, 1995). They found that both types of certainty could speed search. In these experiments and others of this type, keeping target and distractors constant across trials allows participants to know which features to search for from the beginning of the trial, but as Maljkovic and Nakayama (1994) pointed out, it can also produce a form of inter-trial priming in which the target feature seen on one trial is more easily detected on the next trial.

As more and more singleton search experiments have been done, it has become clear that multiple factors are interacting to determine search performance. Awh, Belopolsky, and Theeuwes (2012) have argued that these different factors should be thought of as comprising three different categories. In singleton search, the most obvious is **physical salience**: the difference in color, orientation, size, or some other feature that sets the target apart from all the distractors. This aspect is often described as bottom-up or stimulus driven, because it is determined solely by physical properties of the stimulus. Awh et al. also included the searcher's **current goals** in their framework. When participants know that

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http://dx.doi.org/10.1016/j.visres.2015.08.012
0042-6989/

the target on the upcoming trial will be red, their goal is to attend to red items and to ignore items of other colors. Guidance directed by these goals is often described as top-down. The third category is **selection history**, which includes the inter-trial priming that was first demonstrated by Maljkovic and Nakayama (1994), and has been shown to consist of multiple different factors that affect different processing stages (Huang, Holcombe, & Pashler, 2004; Töllner, Gramann, Müller, Kiss, & Eimer, 2008; Yashar & Lamy, 2011). Within Awh et al.'s framework, the objective is to determine how each of these factors contributes to visual selection, and how they interact with one another. Each of these three factors will play an important role in the experiments described below.

Although all three factors have been the subject of multiple visual search experiments, there is not universal agreement that all three play a role in visual search, especially in search for singletons. Some of the evidence favoring a role for current goals in singleton search comes from Müller, Reimann, and Krumenacher's (2003) search experiments in which participants detected singleton targets more quickly when they knew the dimension of the target. Surprisingly, however, Theeuwes, Reimann, and Mortier (2006) argue that current goals play no role in these singleton searches, and that these effects were instead entirely caused by inter-trial priming, i.e., selection history. Their strongest evidence for this claim comes from their Experiment 2, in which participants search for a singleton after seeing a cue indicating the probable dimension of the target (color or shape). In order to prevent response priming, Theeuwes et al. used a compound search task: after finding the singleton target, participants report the orientation of a line segment within it. The orientation that is reported is independent of the singleton that defines the target, and thus the information from the cue cannot facilitate the choosing of the response. This experiment showed no effect of the cue on search performance, leading Theeuwes et al. to conclude that the goal set by the cue was unable to guide attention to the target.

While Theeuwes et al. (2006) found no cue effects in their Experiment 2, other studies have demonstrated such effects in similar circumstances, including one by Müller and Krummenacher (2006), who added a rating task to prompt participants to use the cue information to establish search goals (see also Leonard & Egeth, 2008, and Zehetleitner, Krummenacher, Geyer, Hegenloh, & Müller, 2011; and see Lamy & Kristjánsson, 2013, and Theeuwes, 2010, 2013, for reviews). Thus, one of the key questions in building theories of attention is whether current goals can be used to guide attention in singleton search, and if so, what factors determine when this guidance is effective and when it is not. The experiments reported here will investigate how search is affected by preknowledge of the target that allows for search goals to be established, with the ultimate objective of understanding interactions among current goals, physical salience, and search history.

The 6 experiments reported in this study investigated the effect of pre-knowledge on visual search for a feature singleton. Specifically, we focused on the following issues: how knowledge of the target dimension could guide search, whether search history could influence the cue validity effect, how an intra-dimensional cue and the type of cue (i.e., word vs. image) contribute to the validity effect, and whether the cost in processing an informative cue would outweigh the benefit provided by the cue. In all the experiments, participants made a speeded response to the orientation of a tilted bar inside a color or shape singleton preceded by either an informative cue (the cue trials) or a non-informative cue (the neutral trials). The cue indicated the likelihood of the singleton having a specific feature (i.e., red) or coming from a specific feature dimension (i.e., color). In Experiment 1, half of the participants received neutral dimensional cues before informative dimensional cues, and this order was reversed for the other half. At first glance, no validity effect was apparent in RTs, but a closer look revealed strong validity effects in both RTs and error rates. In Experiment 2, the two types of trials were intermixed within each block, and a significant validity effect was found. Experiment 3 investigated the effects of intra-dimensional cues and the degree to which the observed validity effect was augmented by priming from the target in a previous trial. Experiment 4 compared the effectiveness of a word cue with that of an image. No difference was found. Experiment 5 found that participants who were provided with an informative cue were outperformed by those who were provided with no cue, suggesting that the cost in processing the cue outweighed the benefit provided by the cue in visual search for a feature singleton. Experiment 6 further showed that participants could ignore informative cues if they began the experiment with neutral cues.

2. Experiment 1

Experiment 1 was modeled after Experiment 2 of Theeuwes et al. (2006), which showed no effects of validity. The task was to judge the orientation of a tilted bar inside a color or shape singleton, with the target display preceded by a cue word that indicated the likely feature-dimension of the singleton. As in Theeuwes et al., a block design was used. In one block, the cue was informative ("Colour" or "Shape"). In the other block, it was non-informative ("Equal"). The experiment had two goals: (1) to determine whether the results of Theeuwes et al. could be replicated with our stimuli; and (2) to investigate whether interblock search history would influence response strategy, which in turn might alter the cue validity effect.

2.1. Method

2.1.1. Ethics statement

This study received prior ethical approval from the University of Canterbury Human Ethics Committee. The study was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Written consent was obtained from the participants.

2.1.2. Participants

Thirty-four students from the University of Canterbury volunteered for the experiment in exchange for course credit or the payment of NZ$10.

2.1.3. Apparatus and stimuli

Stimuli were presented against a white background on a PC with a 16-in. monitor, and E-Prime was used to generate the stimuli and collect responses. Participants were tested individually in a dimly lit room. The viewing distance was about 60 cm.

Each trial consisted of a cue followed by a target display. The cue was a black word written in bold, 18-point Courier New font at the center of the screen. In the neutral condition, the word was "Equal". In the cue condition, it was "Colour" or "Shape" with equal probability. The target display (see Fig. 1) consisted of a central fixation and 6 outline objects each containing a tilted bar. The fixation was a small black cross that subtended .2° in length and width. The 6 objects were located at equal distances along the perimeter of an imaginary circle with a radius of 3.3° and its center at fixation. Five of them were identical black circles, each with a diameter of 1.1°, and the 6th had either a unique color (color singleton) or a unique shape (shape singleton). The color singleton was equally likely to be a red or green circle of the same size as that of the other circles. The shape singleton was equally likely to be a black square that was 1.1° in length and width or a black diamond that was 1.1° along both its horizontal and vertical axes. Each of the 6 objects contained a bar subtending 0.8° in length. Each bar