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# Running the figure to the ground: Figure-ground segmentation during visual search

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ABSTRACT

We examined how figure-ground segmentation occurs across multiple regions of a visual array during a visual search task. Stimuli consisted of arrays of black-and-white figure-ground images in which roughly half of each image depicted a meaningful object, whereas the other half constituted a less meaningful shape. The colours of the meaningful regions of the targets and distractors were either the same (congruent) or different (incongruent). We found that incongruent targets took longer to locate than congruent targets (Experiments 1, 2, and 3) and that this segmentation-congruency effect decreased when the number of search items was reduced (Experiment 2). Furthermore, an analysis of eye movements revealed that participants spent more time scrutinising the target before confirming its identity on incongruent trials than on congruent trials (Experiment 3). These findings suggest that the distractor context influences target segmentation and detection during visual search.



## 1. Introduction

The present work was initially motivated by a consideration of the perceptual task of finding objects in real world settings. Amongst various other processes, searching in the real world necessitates segmenting objects (i.e., figures) from their backgrounds in each region of the search environment the viewer considers. In cluttered everyday environments, the segmentation of figures from the background, as described by the Gestalters (e.g., Rubin, 2001; see also Katz, 1951), is seemingly far from trivial. In the present experiments, using search stimuli that required figure-ground segmentation for the purpose of target and distractor identification, we examined whether search for, and identification of, a figure-ground target image is influenced by the way that surrounding distractors are segmented into figures and grounds.

Our experiments clearly fall at the intersection of two literatures – the visual search literature and figure-ground segmentation literature. In some very important ways, these two literatures have developed along quite different lines. In many laboratory studies of visual search, figure-ground segmentation is simplified by presenting clearly individuated objects (e.g., letters) on homogeneous backgrounds (e.g., uniform grey). Although these studies have provided valuable information about the influence of object features on search performance (e.g., Duncan & Humphreys, 1989; Treisman, 1982; Treisman & Gelade, 1980; Wolfe, 1994), they are necessarily silent on the contribution that figure-ground segmentation makes to search performance. In contrast, studies exploring the principles of figure-ground segmentation have typically eliminated or trivialized any search processes by presenting only a single figure-ground stimulus or efficiently attracting people's attention to the region they are to evaluate as figure or ground (e.g., Peterson & Gibson, 1993).

One notable exception to the foregoing generalisation is a study reported by Hulleman and Humphreys (2004) in which a visual search task was employed to examine principles of figure-ground segmentation. In this study, participants were presented with displays consisting of alternating upright and inverted pyramids, with each pyramid being made up of horizontal rectangles of variable lengths. The upright and inverted irregular pyramids appeared as if they were interlocking. The display included two colours, with the upright pyramids sharing one colour and the inverted pyramids sharing the other colour. As such, the displays could be perceived either as consisting of upright pyramids against a uniform background or as consisting of inverted pyramids against a uniform background. In the search task, participants were required to search for the unique symmetrical pyramid among other asymmetrical pyramids that served as distractors. Participants were

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informed of the colour of the target before each trial began. The striking result was that upright target pyramids were found faster and with greater accuracy than inverted target pyramids. This result has implications for both figure-ground segmentation and visual search. With regard to figure-ground segmentation, the finding suggests that observers preferentially parse the upright pyramids as figures and the inverted pyramids as ground, thus supporting the conclusion that "top-bottom polarity" is a cue for figure-ground segmentation. With regard to visual search, the finding suggests that the objects of search are dependent on figure-ground segmentation processes differentiating them as figures, and that if a target region is predisposed to be parsed as ground, it becomes more difficult to identify as a target of search.

In addition to the study by Hulleman and Humphreys (2004), which effectively combined the visual search and figure-ground literatures, there is also a notable commonality between the two literatures: namely, both literatures address the issue of *context effects* in perception. In the figure-ground segmentation literature, several studies have now clearly demonstrated that separation of a figure from the background depends not only on local elements defining the figural object, such as closure (e.g., Kovacs & Julesz, 1993; for comprehensive lists see Fowlkes, Martin, & Malik, 2007; Harrower, 1936; Palmer, 1999), but also on the other elements present in the periphery of the scene (Lamme, 1995; Peterson & Salvagio, 2008). For instance, using a perceptual judgment task, Peterson and Salvagio (2008) found that an area defined by a convex edge was more likely to be judged as a 'figure' as the number of adjacent alternating convex and homogenously-coloured concave edges increased. This led them to conclude that "figure-ground determinations at a single edge are influenced by figure-ground determinations at distant disconnected edges" (Peterson & Salvagio, 2008, p. 9). In other words, it appears that the way figure-ground segmentation unfolds in one region of the visual field can form a context that may influence figure-ground segmentation in another region.

Context effects also play an important role in visual search. In fact, the study of visual search is often effectively – though not often framed as such – a study of *context effects*. Studies of visual search typically vary the relation between a target and a set of distractors (such as the visual similarity of targets and distractors; Duncan & Humphreys, 1989), and examine how this influences detection or identification of the target. Thus, the distractors serve as the context in which the target is detected. One of the chief goals of visual search studies is to describe important context effects relevant for search, for instance, showing that a long line among short lines is more easily found than a short line among long lines, and that this difference increases with the number of contextual distractors (Treisman & Gormican, 1988; Experiments 1 and 1a). Identifying these 'context effects' in visual search is important because they provide constraints for theories about the processes underlying search. The foregoing example of searching for lines of different lengths, for instance, led to the proposal that the early visual system includes feature maps that guide attention, and that these feature maps contain information about the presence but not the absence of features (Treisman & Gormican, 1988). Other findings suggest that during visual search distractor items can provide contextual information that can influence how a search target is visually interpreted (Rauschenberger et al., 2004). Thus, visual search provides a useful tool for studying context effects, and the resulting context effects are informative about the nature of underlying search mechanisms.

### 1.1. The present study

In the present experiments, using search stimuli that required figure-ground segmentation for the purpose of target and distractor identification, we examined whether the segmentation of contextual distractors influenced the segmentation and detection of a target item during visual search. In our task, we had participants search a matrix of black-and-white Gestalt figure-ground images. Some of these images were reproduced from previous work (Gibson & Peterson, 1994; Peterson et al., 1998; Peterson & Gibson, 1991, 1993, 1994b; see "Research" tab at http://www.u.arizona.edu/~mapeters/), others were generated by the authors, and additional images were found and modified by the authors. Fig. 1 illustrates some examples of figure-ground images used in our experiments. In each image, one of the two regions (either the black *or* white region), approximately equal in size, depicted a meaningful object, whereas the other region depicted a less meaningful shape (Gibson & Peterson, 1994; Peterson et al., 1998; Peterson & Gibson, 1991, 1993, 1994b). For example, in Fig. 1, the image on the left depicts a black boat on a white background, whereas the image on the right depicts a white tree on a black background. We used images such as these because it has been shown that regions depicting a meaningful object are rapidly perceptually segmented as figures, while regions depicting less meaningful shapes are segmented as background (see Gibson & Peterson, 1994; Peterson et al., 1998; Peterson & Gibson, 1991, 1993, 1994b). While we manipulated meaningfulness of the two regions in each image, we left other figural cues that may affect figure-ground assignment to vary (e.g., symmetry, Peterson & Gibson, 1994a; top-bottom polarity, Hulleman & Humphreys, 2004). For the search task, participants were instructed to locate a pre-specified target image embedded in a matrix of distractors. Presenting numerous figure-ground images in a matrix created the opportunity for segmentation to occur in multiple regions of the search array (until the target was found).

The critical manipulation in each of our experiments was the colour-congruency of the target and distractor images. For each trial, the meaningful regions in all of the distractor images were the same colour (i.e., the regions depicting a meaningful object were either all white or all black), whereas the colour of the meaningful region in the target image was either the same as (congruent trials) or different than (incongruent trials) the colour of the meaningful regions of the distractor images. In other words, on a congruent trial, the meaningful region in all of the images (target and distractors) was the same colour (e.g., black). In contrast, on an incongruent trial, the meaningful region of all distractor images was the same colour (e.g., black) whereas the meaningful region of the target was the opposite colour (e.g., white).

This experimental design allowed us to assess the possibility – consistent with previous demonstrations of contextual effects on figure ground segmentation (Peterson & Salvagio, 2008; see also Lamme, 1995) – that the figure-ground segmentation of the distractors on a given trial might influence detection of the target item on that trial. On this view, as the participant searches the display, parsing might be increasingly influenced by the repeated exposure to, and parsing of, the distractors, since all of the meaningful regions of the distractors have the same colour. Specifically, if the meaningful regions of all the distractors are white, white regions might be more likely to be parsed as the expected figure. Conversely, if meaningful regions in all the distractors are black, black regions might be more likely to be parsed as the expected figure. If this way of parsing distractors is applied to the target item, it may influence target recognition such that segmentation of the target is affected not only by the relative meaningfulness of the two target regions, but also by the parsing bias acquired while viewing the distractors. On congruent trials, the meaningfulness cue to figural segmentation and the bias created by parsing distractors would favour the same region to be segmented as figure (i.e., the region depicting a meaningful object), thus leading to a relatively effective segmentation of the target. In contrast, on incongruent