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Effects of target and distractor heterogeneity on search for a color target

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Abstract

Experiments were designed to investigate the effects of target and distractor heterogeneity on the threshold for detection of a color target in a search task. In the first two experiments stimuli were chosen so that the target and distractor stimuli varied along one Cardinal axis in color space, while the target differed from distractors along another Cardinal axis. The Cardinal axis signaling the relevant target–distractor difference was consistent from trial to trial within an experiment. When observers searched for a color target among homogeneous distractors but the color of the target and distractors changed from trial to trial there was a small increase in threshold. When the distractors within a display were heterogeneous, and the target color varied from trial to trial there was a larger and more consistent increase in threshold. Varying stimuli along a Cardinal axis other than the Cardinal axis that differentiates target and distractors can impair performance in visual search tasks. Further experiments showed that the presence of heterogeneous distractors had little or no effect on thresholds when location or color cues indicated that these stimuli were irrelevant to the task. Results suggest that the effect of heterogeneity in these experiments is attentional in nature rather than sensory.

Keywords: Attention; Color; Visual search

1. Introduction

The effect of stimulus heterogeneity on visual search has been the subject of many previous studies and these studies provide a rather diverse variety of results and interpretations of heterogeneity effects. Different studies have found that increasing the heterogeneity of the stimuli can hinder performance, have no effect on performance, or improve performance. Results from different studies may vary in part because the heterogeneity in the stimuli has been introduced in different ways in different studies.

2. Ways in which heterogeneity can vary

Treisman (1988) distinguished between target heterogeneity effects and distractor heterogeneity effects and attributed them to different underlying causes. As an example of target heterogeneity effects, Treisman (1988) described experiments in which the same set of homogeneous distractors was presented from trial to trial. Search times for single targets that varied from trial to trial were longer than search times for targets that were consistent from trial to trial. The effect was larger if the targets varied along two different feature dimensions (i.e. color and orientation), than if the targets varied in a single feature dimension (i.e. in color only, or orientation only). Target heterogeneity effects were attributed to the need to attend to different neural "modules" coding different feature dimensions.

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To study distractor heterogeneity effects, Treisman (1988) presented the same target from trial to trial, but the distractors within each display varied. When distractors within each display varied along the same feature dimension (e.g. distractors were red, green, or white) that distinguished the blue target from the distractors (e.g. color), the search times were much longer than search times with distractors that were homogeneous within each display. When the blue target was presented among distractors that varied in orientation rather than color (e.g. green rectangular bars oriented either horizontally or vertically) the heterogeneity had no effect on search times, which were similar to search times with homogeneous distractors. Thus target and distractor heterogeneity had the same effects on the search-relevant dimension but different effects on the search-irrelevant dimension. The effect of distractor heterogeneity along the feature dimension defining the target was attributed to a reduction in the perceptual differences between the target and distractors within the feature coding "module" used to discriminate the target and distractors. Target heterogeneity effects were attributed to high-level processes involving the direction of attention while distractor heterogeneity effects were attributed to low-level sensory processes within the feature mechanisms coding the target and distractors. Subsequently, Duncan and Humphries (1989), Wolfe (1994), Palmer, Verghese, and Pavel (2000), and Rosenholtz (1999, 2001a, 2001b) also presented formulations of distractor heterogeneity effects in terms of the coding of sensory differences between targets and distractors and the representation of the stimuli.

3. Brief review of heterogeneity effects in color search

Target and distractor heterogeneity need not be confined to separate experiments as in the Treisman (1988) studies, and in subsequent studies of heterogeneity effects in color search, various types of target and distractor heterogeneity were sometimes combined within the same experiment. For example, Bravo and Nakayama (1992) investigated a heterogeneity effect that might be regarded as involving heterogeneity in both targets and distractors. In different blocks of homogeneous trials observers searched for a red target among homogeneous green distractors or a green target among homogeneous red distractors. In the heterogeneity condition the two types of displays were randomly intermixed so that both the color of the targets and the homogeneous distractors might change from trial to trial. Searches in homogeneous conditions were consistently about 10% faster than in heterogeneous conditions across several stimulus set sizes for three different observers. Maljkovic and Nakayama (1994) attributed the difference between homogeneous and heterogeneous conditions to priming by a form of involuntary short-term implicit memory. Their explanation of this heterogeneity effect might be regarded as a high-level explanation because it involves short-term memory and the direction of attention rather than sensory-perceptual differences. Alternatively, the increase in response time in the heterogeneous condition in the Bravo and Nakayama (1992) study might be attributed to the possibility that observers needed to attend to different neural color coding mechanisms that code redness and greenness in the mixed condition, while they need only attend to one neural color-coding mechanism in the blocked conditions. DeValois and DeValois (1993), Billock, Gleason, and Tsou (2001), and Valberg (2001) have recently proposed models of color coding that suggest that red and green may be signaled by different neural mechanisms rather than a single red-green mechanism as suggested by earlier models. The need to attend to larger numbers of noisy signals in larger numbers of neural feature coding mechanisms has been shown to take more processing time (Monnier & Nagy, 2001a; Treisman, 1988) or raise threshold (see Davis, Kramer, & Graham, 1983; Graham, 1989; Monnier & Nagy, 2001b; Palmer, Aimes, & Lindsay, 1993; Palmer et al., 2000).

Palmer and Teller (1993) reported another experiment in which target and distractor heterogeneity were combined in a search accuracy task. In the heterogeneity condition, distractors within each display varied in color appearance, and the color appearance of the target also varied from trial to trial. Eight stimuli were presented on each trial and each stimulus was a different color. The same set of distractor colors was presented on each trial. The variation in the color of the distractors was chosen in a systematic way. For example, in one condition distractors varied in hue or chromaticity but were all set to the same luminance. The targets differed from distractors in luminance or along the third Cardinal axis of color space (see Krauskopf, Williams, & Heeley, 1982). Targets varied across trials because the increment in luminance could be added to any one of the eight distractor colors. The Cardinal axes in color space are thought to represent independent neural color-coding mechanisms (see Derrington, Krauskopf, & Lennie, 1984; Lennie & D'Zmura, 1988). Therefore, the variation in the color of the target and distractors should have had no effect on signals in the neural color-coding mechanism that signaled the difference between the target and the distractors, and this color-coding mechanism was consistent from trial to trial. If these mechanisms can be identified as feature maps in Treisman's (1988) terminology, we might expect that there should be no effect of heterogeneity in this experiment. However, thresholds were approximately 50% higher in the heterogeneity conditions than in conditions with distractors that were homogeneous within each display and targets that were homogeneous across trials. One possible inter-