Spatial interactions in simple and combined-feature visual search

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Abstract—To isolate the mechanisms responsible for spatial interactions in visual search, we investigated the effects of inter-element distance and positional jittering in both simple (V in/s) and combined-feature (inverted V inVs) search tasks in which the observer had to find a target in a background of similar nontargets. Thresholds, defined as the stimulus duration for 75% correct, were measured for ‘present’ and ‘absent’ target conditions as a function of background numerosity (ranging from 4 to 64 background elements), independently for four inter-element distances and three positional jittering conditions.

Results show: (1) both simple and combined-feature search involve a parallel, capacity limited process, (2) thresholds for parallel search of simple features are directly related to inter-element distance whereas this has little effect on thresholds in combined-feature search, and (3) positional jittering has a direct effect on thresholds in combined-feature search and an inverse effect in simple-feature search. These results indicate that two different mechanisms of spatial interactions are involved in parallel search. The activation of each of the two mechanisms depends on the stimulus used. In parallel search for simple and dissimilar features, the underlying mechanism is a short-range one, based on lateral inhibition, whereas the parallel search for combined and similar features is based on a nontarget grouping mechanism which relies on facilitatory interactions between regular elements.

INTRODUCTION

In the last 20 years many studies have suggested a distinction between pre-attentive and attentive visual processing (Neisser, 1967; Treisman and Gelade, 1980; Julesz, 1981). Pre-attentive processing consists of parallel processing of visual information in many positions at the same time. Attentive processing instead, is assumed to operate serially over more limited spatial areas.

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One important question concerns the mechanism that enables parallel detection of a target embedded in an array of nontargets. One answer is to postulate a processing stage where different features are represented separately in feature maps without access to spatial information or feature locations. The detection of single-feature targets depends on the total (global) activity at the corresponding map (Treisman, 1985). If nontargets and targets activate different maps, the presence and number of nontargets should not influence detecting activity in the target map.

An alternative model assumes that parallel, pre-attentive processing depends on the interaction between low-level detectors tuned to spatial frequency and orientation (Beck et al., 1987; Chubb and Sperling, 1988; Fogel and Sagi, 1989; Bergen and Landy, 1991). In this model, a set of partially overlapping linear detectors, all sensitive to the same spatial frequency and orientation is assumed to be the neural base of a channel (Sutter et al., 1989). These detectors, forming the units of a channel, are like a set of simple cortical cells all having receptive fields of the same shape, size and sensitivity. Since it has receptive fields spread over the whole visual field, the channel can be a good mechanism for parallel processing of the elements in the visual field (Watson, 1983; Graham, 1989). This assumption relies on the experimental evidence that channels with overlapping receptive fields are not independent and receive inhibitory inputs from channel coding for neighboring spatial frequencies or orientations and disinhibitory inputs from channels behind these inhibitory regions (De Valois, 1977; Tolhurst and Dean, 1987).

In visual search studies, two sets of data suggest that parallel processing depends on the local spatial interactions between spatial filters. One set shows a strong dependence of pre-attentive detection on inter-element distance. Detection of feature differences (orientation of line segments) is found to improve with increasing element density both in texture discrimination (Nothdurft, 1985) and search tasks (Sagi and Julesz, 1987; Sagi, 1990). The second set refers to the effect of spatial regularity on the visual search. In search for combined-feature, if nontarget elements are regularly arranged, the search function becomes almost flat (Humphreys et al., 1989) whereas positional jittering contributes to make the search function linearly increasing. Thus, improved detection with regular nontargets could depend on the activation of a mechanism pooling from a regular patch of elements (Moulden, 1994).

These effects have been interpreted as evidence that parallel detection is based on the activation of a network with excitatory and inhibitory local connections between orientation sensitive mechanisms (Sagi, 1990).

For instance, the improvement in search for simple feature differences with increasing element density (Sagi and Julesz, 1987; Sagi, 1990) has been considered indicative of inhibitory interactions which reduces the visual system response to uniform textural fields and enhance texture borders.

On the other hand, the reduction of the slopes of search functions with regular patterns in the combined-feature search (Humphreys et al., 1989) suggests that