



Research Note

Parallel Search for a Conjunction of Contrast Polarity and Shape

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When a target object embedded in an array of other objects can be distinguished along a single feature dimension (e.g. color or shape), it can be detected in parallel. When a target object is defined by a conjunction of stimulus features, at least some serial search is required, indicating that the visual system is less efficient in conducting a parallel search over two stimulus dimensions simultaneously. Some exceptions to this finding have been reported. The present results suggest another exception: search for a conjunction of contrast polarity and shape can be conducted in parallel while the same conjunction consisting of color and shape requires some serial search. The neurophysiological implications are discussed.

Visual search Parallel processing Feature conjunction Contrast polarity

INTRODUCTION

In visual search, the observer has to decide whether or not a specified target is present in the array of elements. When the target differs from all other elements in one dimension, it is seen immediately without effort; a phenomenon known as visual "pop-out" (Treisman & Gelade, 1980; Treisman, 1986). One can speak of a "pop-out" when the time to detect the target is hardly affected by the number of elements in the display [less than 5 or 6 msec per element (Treisman & Souther, 1985)], indicating that the target can be detected in parallel. Parallel detection occurs when the target can be distinguished along a single dimension (e.g. color or shape). According to the original Feature Integration Theory (Treisman & Gelade, 1980) when a target is defined by the conjunction of two stimulus dimensions, search has to be conducted serially, implying that time to find the target increases with the number of elements in the display. Serial search is required because the visual system is less efficient in conducting a parallel search over two dimensions simultaneously. Some exceptions to this finding have been reported. One dimension can be searched in parallel if the other dimension is stereoscopic depth (Nakayama & Silverman, 1986), or relative motion (McLeod, Driver & Crisp, 1988). Note that more recent visual search theories (e.g. Duncan & Humphreys, 1989; Cave & Wolfe, 1990) have questioned the strict distinction between parallel and serial search. These

theories claim that search difficulty (i.e. serial/parallel search) basically depends on the similarity between target and nontarget elements.

In the present experiment, observers performed a classic conjunction search task (e.g. Treisman & Gelade, 1980) in which they searched for a target letter O in an array of Xs, intermingled with Os of either a different color, or a different polarity. In order to detect the target a *conjunction* of features (either shape and color, or shape and polarity) was required. Although the target was defined by a conjunction of features, the present study shows that a shape and polarity conjunction can be detected in parallel indicating that the target "pops-out" within a group of elements having opposite polarities. The search for a classic color \times shape conjunction, on the other hand, is slower and less efficient in line with Treisman and Gelade (1980).

METHOD

Subjects

Data were collected from two trained observers (the authors) and one naive subject (KH). All had corrected-to-normal vision and reported having no color defects as confirmed by the standard color vision tests.

Apparatus and stimuli

The stimulus field consisted of either 8, 18, 26, or 36 randomly distributed elements arranged within a slightly irregular 6×6 array, subtending 7.3×6.8 deg of visual angle. Individual letters subtended 0.36×0.21 deg. A SX-386 personal computer with a NEC Multisync 3D

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VGA color CRT (640 × 350 pixels) controlled the timing of events, generated pictures and recorded reaction times. A target was present in half of the trials. Observers responded *yes* (target present) or *no* (target not present) by pressing the appropriate response keys on the keyboard. The observer sat in a sound-attenuated, dimly lit room with his head resting on a chinrest 90 cm from the screen. In the polarity condition, letters were either white (130 cd/m²) and black (0.03 cd/m²) on a gray (42 cd/m²) background. In the color condition, the letters were red ($x,y = 0.627/0.353$; $Y = 10.2$ cd/m²) and green ($x,y = 0.309/0.593$, $Y = 14.7$ cd/m²) on a dark (0.4 cd/m²) background.

Procedure

In the conjunction search condition, observers searched for a target letter O in an array of Xs, intermingled with Os of either a different color, or a different polarity. Specifically, between blocks of trials, in the color conjunction condition, observers either searched for a red O among red Xs and green Os, or the reverse: a green O among green Xs and red Os. In the polarity conjunction condition, observers either searched for a black O among black Xs and white Os, or the reverse: a white O among white Xs and black Os. Figure 1 provides examples of the trial events.

In the feature search condition, observers searched for the target letter O that could be distinguished from the other elements either by its unique polarity or its unique shape (condition: P or S), or either by its unique color or its unique shape (condition: C or S). Display size (8, 18, 26, 36) was randomized within blocks from trial to trial. Each block consisted of 208 trials. The two experienced observers performed both four blocks of feature search trials and four blocks of conjunction search trials. The naive observer only performed four blocks of conjunction search trials. Before each block of trials observers were told about the upcoming condition. Observers were instructed to respond as fast as possible, while minimizing errors. A beep informed the observers when an error was committed. Erroneous response were

discarded. The display remained on until a response was emitted up to a maximum of 2 sec.

RESULTS AND DISCUSSION

The time to detect the target defined by a conjunction of polarity and shape barely depends on the number of distracting elements, while present and absent responses are practically equally fast [Fig. 2(A)]. Table 1(A) gives the search slope for target present and absent trials. Control conditions are shown in Fig. 2(B) and Table 1(B). As expected (Treisman & Gelade, 1980; Treisman, 1982, 1986), feature search for a unique shape, unique color, and unique polarity all are parallel. Since the search slopes for a target defined by a polarity × shape conjunction are essentially flat for both target present and absent responses, they basically do not differ from those obtained with feature search, suggesting that the observers can search for the conjunction target as if they were searching for a simple feature. In other words, the target letter O pops-out within a group of elements that has an opposite luminance contrast enabling parallel search in one group without interference from elements of the other group. As clear from Table 1, search for a black target between black and white elements is as efficient as search for a white target between black and white elements, showing that the effect of polarity cannot be due to a reduced visibility of either subgroup of elements.

In line with earlier work (Treisman & Gelade, 1980), the time to detect a target that is defined as a color × shape conjunction increases with the number of distracting elements. Note that the search slopes are about 8 msec/item for target present trials and about 18 msec/item for target absent trials, slopes which are a little less than half of those observed in more classic conjunction search tasks. For example, Treisman and Gelade (1980) report slopes of 20.5 and 39.5 msec/item for target present and absent trials when searching for a red O between green Os and red Ns. As demonstrated by Egeth, Virzi and Garbart (1984), when subsets of

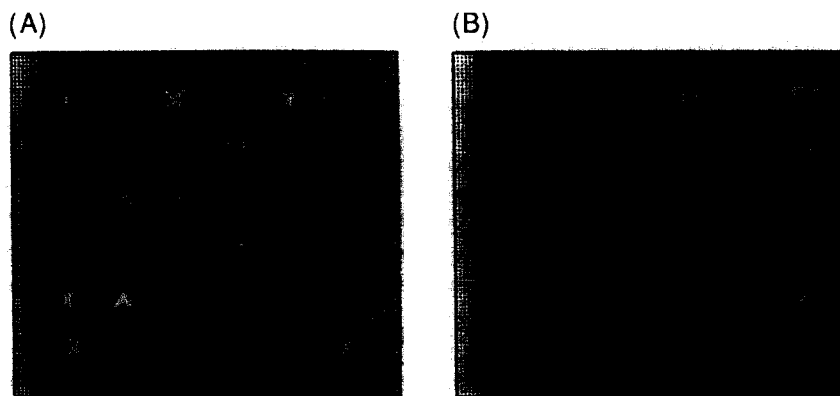


FIGURE 1. Example of display size 26. Shown are the contrast polarity and shape conjunctions. The white target letter O was embedded between black Os and white Xs on a gray background (A). The black target letter O was embedded between white Os and black Xs (B).

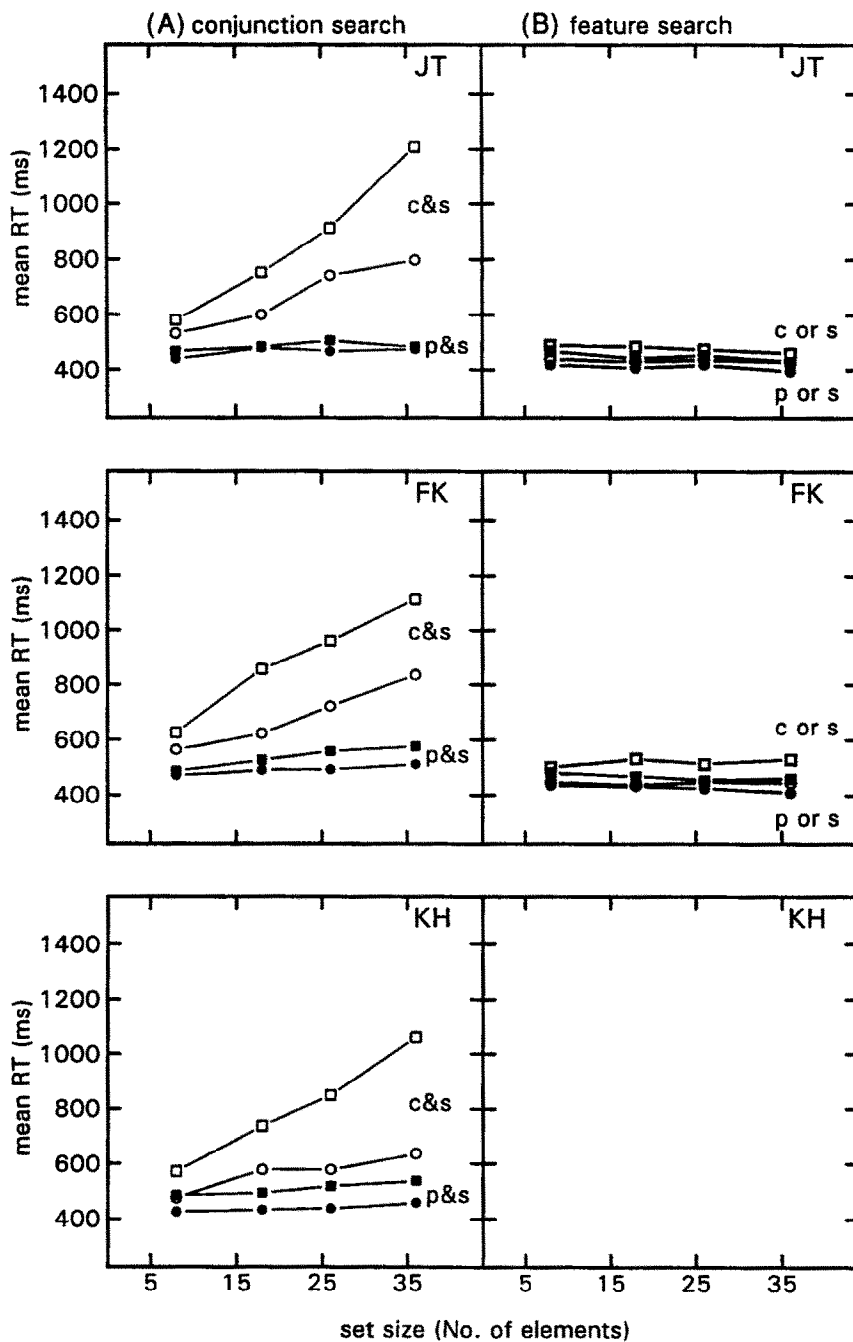


FIGURE 2. (A) Time to detect the presence (circles) or absence (squares) of targets that can be distinguished on the basis of a conjunction of features as a function of the number of elements in the display. Solid symbols represent color (c) and shape (s), open symbols represent polarity (p) and shape (s). (B) Panels on the right represent the control conditions in which observers search for the letter O that could be distinguished from the other elements either by its unique polarity or its unique shape (condition: p or s), or either by its unique color or its unique shape (condition: c or s).

elements are salient enough, rather than searching all elements in the display, subjects may limit their search to one subset (e.g. serial search among only the red elements). The presently found relatively shallow serial search slopes suggest that the color differences were large enough to allow “guided” serial search among a subset of elements giving search slopes which are about half those found in more classic search tasks. The observation that the search slope for target present trials is about half the slope for target absent trials suggests that search among a subset is serial and self-terminating.

Other even faster serial “guided” searches have been reported. Wolfe, Cave and Franzel (1989) showed that color \times orientation conjunctions can be found quite efficiently. For example, in a condition in which colored elements were presented on a black background, search for a red, left, oblique line among green, left obliques and red right obliques gave search slopes of 6.1 msec/item for target present trials and 13.1 msec/item for target absent trials (Expt 7). Wolfe *et al.* (1989) and Cave and Wolfe (1990) suggested that in case of conjunction search subjects do not search randomly through a

TABLE 1. Reaction time as a function of the number of elements in the display (msec/element)

(A)	Polarity and shape		Color and shape	
	Black	White	Red	Green
Conjunction search				
<i>Target present</i>				
JT	1.23	0.92	8.60	11.48
FK	0.92	1.76	9.84	9.94
KH	1.77	0.42	5.50	5.18
<i>Target absent</i>				
JT	0.76	0.69	24.19	20.25
FK	3.57	2.96	14.56	19.88
KH	1.20	2.67	17.17	17.27

(B)	Polarity and shape		Color and shape	
	Black	White	Red	Green
Feature search				
<i>Target present</i>				
JT	-0.41	-0.92	-0.50	-0.15
FK	-1.34	-0.51	-0.58	0.63
<i>Target absent</i>				
JT	-1.97	-0.41	-0.46	-0.80
FK	-0.07	-1.61	1.36	0.33

display but serially inspect only those items that are likely to be the target. These and other studies (Duncan & Humphreys, 1989; Treisman & Sato, 1990) have questioned the qualitative distinction between parallel and serial search as proposed in the original Feature Integration Theory (Treisman & Gelade, 1980).

The present findings suggest that attention can be directed more selectively to separate groups of elements having opposite polarities than to groups having different colors. What could be the underlying mechanism responsible for this difference? Two of the exceptions reported previously have been attributed to the existence of separate physiological channels for stereo disparity (Nakayama & Silverman, 1986) and motion (McLeod *et al.*, 1988), each located in the visual cortex (DeYoe & Van Essen, 1988; Livingstone & Hubel, 1987). The white and black elements in our display are expected to be processed by separate pathways, namely the ON-center and OFF-center ganglion cells (Kuffler, 1953), located in the retina. The ON-center and OFF-center ganglion cells have been shown to anatomically segregate in two distinct laminae of the retinal inner plexiform layer (Wässle, Peichl & Boycott, 1983; Nelson, Famiglietti, Kolb, 1978), which remain segregated at least through the lateral geniculate nucleus (Schiller, 1984). Our results provide supporting evidence that subjects are able to independently sample from either channel, suggesting that the ON-OFF segregation remains intact throughout the visual system (Fiorentini, Baumgartner, Magnussen, Schiller & Thomas, 1990).

Similar findings involving contrast polarity have been reported in letter recognition tasks. In these tasks, letter recognition is profoundly affected by the presence of

neighboring contours, especially in the peripheral visual field. This interaction is strongly reduced if the target letter differs from the flanks in its stereo disparity or contrast polarity (Kooi, Tripathy & Levi, 1994). The present study and that of Nakayama and Silverman (1986) show that a conjunction target with one of these factors results in parallel search. For this reason Kooi *et al.* (1994) have suggested that pre-attentive pop-out and contour interaction may be distinct yet related processes.

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