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PARALLEL SEARCH FOR A CONJUNCTION OF SHAPE AND CONTRAST POLARITY

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Korte samenvatting van:
Parallel zoeken naar een conjunctie-target van vorm en contrast-polariteit
Dr.ing. J. Theeuwes en dr. F.L. Kooi
16 maart 1994, Rapport TM 1994 B-6
TNO Technische Menskunde[1], Soesterberg

MANAGEMENT UITTREKSEL

Een object dat zich van andere objecten onderscheidt op één dimensie (b.v. kleur of vorm), kan d.m.v. parallelle verwerking gedetecteerd worden. Wanneer een object bestaat uit een conjunctie van stimulus dimensies (b.v. kleur en vorm), dient het visuele veld, serieel afgezocht te worden wat suggereert dat het visuele systeem niet in staat is parallel te zoeken onder twee stimulus dimensies tegelijkertijd. Eerder onderzoek heeft laten zien dat hierop twee uitzonderingen zijn. Eén dimensie kan parallel afgezocht worden wanneer de andere dimensie bestaat uit stereoscopische diepte (Nakayama & Silverman, 1986) of bestaat uit relatieve beweging (McLeod, Driver & Crisp, 1988). Deze studie laat een derde uitzondering zien: wanneer één dimensie bestaat uit contrast-polariteit kan de andere dimensie (vorm) parallel afgezocht worden. Neurofysiologische implicaties worden besproken.

[1] Per 1 februari 1994 is de naam Instituut voor Zintuigfysiologie TNO gewijzigd in TNO Technische Menskunde.

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SUMMARY

When a target object embedded in an array of other objects can be distinguished along a single feature dimension (e.g., colour or shape), it can be detected in parallel. When a target object is defined by a conjunction of stimulus features, search has to be conducted serially, indicating that the visual system is incapable of conducting a parallel search over two stimulus dimensions simultaneously. Earlier research has shown that there are two exceptions to this finding. One dimension can be searched in parallel if the other dimension is stereoscopic depth (Nakayama & Silverman, 1986), or relative motion (McLeod, Driver & Crisp, 1988). We report a third exception: if one dimension involves contrast polarity, another dimension (shape) can be searched in parallel. The neurophysiological implications are discussed.

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Parallel zoeken naar een conjunctie-target van vorm en contrast-polariteit

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SAMENVATTING

Een object dat zich van andere objecten onderscheidt op één dimensie (b.v. kleur of vorm), kan d.m.v. parallelle verwerking gedetecteerd worden. Wanneer een object bestaat uit een conjunctie van stimulus dimensies (b.v. kleur en vorm), dient het visuele veld, serieel afgezocht te worden wat suggereert dat het visuele systeem niet in staat is parallel te zoeken onder twee stimulus dimensies tegelijkertijd. Eerder onderzoek heeft laten zien dat hierop twee uitzonderingen zijn. Één dimensie kan parallel afgezocht worden wanneer de andere dimensie bestaat uit stereoscopische diepte (Nakayama & Silverman, 1986) of bestaat uit relatieve beweging (McLeod, Driver & Crisp, 1988). Deze studie laat een derde uitzondering zien: wanneer één dimensie bestaat uit contrast-polariteit kan de andere dimensie (vorm) parallel afgezocht worden. Neurofysiologische implicaties worden besproken.

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1 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-ms 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 (for example, colour or shape). When the target is defined by the conjunction of two stimulus dimensions, search is conducted serially, implying that the time to find the target increases with the number of elements in the display. This finding suggests that the visual system is incapable of conducting a parallel search over two dimensions simultaneously.

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 colour, or a different polarity. In order to detect the target a *conjunction* of features (either shape and colour, 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.

2 METHOD

2.1 Subjects

Data were collected from two trained observers (the authors). Both had corrected-to-normal vision and reported having no colour defects as confirmed by the standard colour vision tests.

2.2 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° of visual angle. Individual letters subtended 0.36° × 0.21°. A SX-386 Personal Computer with a NEC Multisync 3D 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 grey (42 cd/m²) background. In the color condition, the letters were red (x,y= .627/.353; Y= 10.2 cd/m²) and green (x,y=.309/.593, Y=14.7 cd/m²) on a dark (0.4 cd/m²) background.

2.3 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.

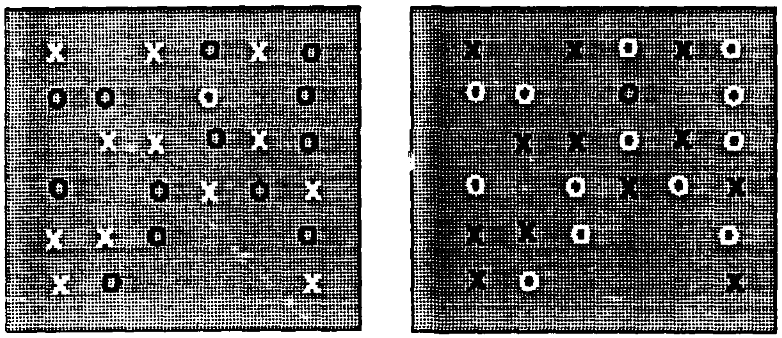

Fig. 1 Example of Display Size 26. Shown are the contrast polarity and shape conjunctions. The white target letter O was embedded between black Os and white Xs on a grey background (left panel); The black target letter O was embedded between white Os and black Xs (right panel).

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. In total each observer performed 4 blocks of feature search trials and 4 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 responses were discarded. The display remained on until a response was emitted up to a maximum of 2 s.

3 RESULTS AND DISCUSSION

In line with earlier work (Treisman & Gelade, 1980), the time to detect a target that is defined as a conjunction of color and shape increases with the number of distracting elements (Fig. 2A). Table 1A gives the search slope for target present and absent trials.

Table I Reaction time as a function of the number of elements in the display (ms/element).

A)

conjunction search	polarity & shape		colour & shape	
	black	**white**	**red**	**green**
target present				
JT	1.23	0.92	8.60	11.48
FK	0.92	1.76	9.84	9.94
target absent				
JT	0.76	0.69	24.19	20.25
FK	3.57	2.96	14.56	19.88

B)

feature search	polarity or shape		color or shape	
	black	**white**	**red**	**green**
target present				
JT	-0.41	-0.92	-0.50	-0.15
FK	-1.34	-0.51	-0.58	0.63
target absent				
JT	-1.97	-0.41	-0.46	-0.80
FK	-0.07	-1.61	1.36	0.33

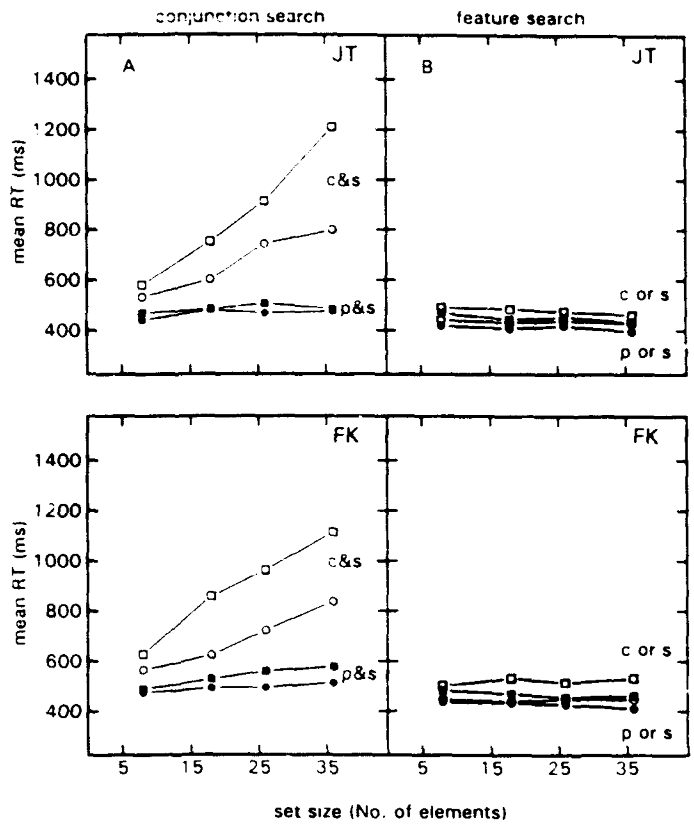

Fig. 2 A: Time to detect the presence (circles) or absence (squares) of targets that can be distinguished on the basis of a conjunction of features (left panels) as a function of the number of elements in the display. Filled symbols represent color (C) and shape (S), open symbols represent polarity (P) 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).

Note that the search slopes are about 10 ms/item for target present trials and about 20 ms/item for target absent trials, slopes which are about half of those observed in more classic conjunction search tasks. For example, Treisman and Gelade (1980) report slopes of 20.5 ms/item and 39.5 ms/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 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). Other fast serial "guided" searches have been reported before. Wolfe, Cave and Franzel (1989) showed that color × orientation conjunctions can be found quite efficiently. For example, in a condition in which coloured 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 ms/item for target present trials and 13.1 ms/item for target absent trials (Exp. 7). Wolfe et al. (1989, Cave & Wolfe, 1990) suggested that in case of conjunction search subjects do not search randomly through a display but serially inspect only those items that are likely to be the target. 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.

Unlike fast serial "guided" search as found with the color × shape conjunction, the time to detect a target defined by a conjunction of polarity and shape barely depends on the number of distracting elements, while present and absent responses are equally fast. Control conditions are shown in Figure 2B and Table 1B. As expected (Treisman & Gelade, 1980; Treisman, 1982, Treisman, 1986), feature search for a unique shape, unique color, and unique polarity all are parallel.

The results indicate that the search slopes for a target defined by a conjunction of polarity and shape are essentially flat for both target present and absent responses. Both slopes are much flatter than the 5 or 6 ms/item that is generally assumed to be the criterion for a pop-out (Treisman & Souther, 1985). Basically, the shape and polarity conjunction search slopes do not differ from those obtained with feature search, suggesting that the observers can be trained to 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.

The present findings suggest that attention can be directed selectively to separate groups of elements having opposite polarities, but not to groups having different colours. What could be the underlying mechanism responsible for this difference? The two exceptions reported previously have been attributed to the existence of separate physiological channels for stereo disparity (Nakayama & Silverman, 1986) and motion (McLeod, Driver & Crisp, 1988), each located in the visual cortex (DeYoe & Van Essen, 1988; Livingstone & Hubel, 1987). The white and black elements in our display are also processed by separate pathways, namely the ON-centre and OFF-centre ganglion cells (Kuffler, 1953), located in the retina. The ON-centre and OFF-centre 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 show that subjects are able to independently sample from either channel suggesting that the ON-OFF segregation remains intact throughout the visual system (Fiorentini et al., 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 neighbouring 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 et al., 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.

REFERENCES

Cave, K.R. & Wolfe, J.M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology* 22, 225-271.

DeYoe, E.A. & Van Essen, D.C. (1988). Concurrent processing streams in monkey visual cortex. *Trends in Neurosciences* 11.

Egeth, H.E., Virzi, R.A. & Garbart, H. (1984). Searching for conjunctively defined targets. *Journal of Experimental Psychology: Human Perception and Performance* 10, 32-39

Fiorentini, A., Baumgartner, G., Magnussen, S., Schiller, P.H. & Thomas J.P. (1990). In: L. Spillmann & J.S. Werner (Eds), *Visual Perception The Neurophysiological Foundations* (pp. 129-161). San Diego: Academic Press.

Kooi F.L., Toet A., Tripathy S.P. & Levi, D.M. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spatial Vision*, in press.

Kuffler, S.W. (1953). Discharge patterns and functional organization of mammalian retina. *Journal of Neurophysiology* 16, 37-68 (1953)

Livingstone, M.S. & Hubel, D.H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *Journal of Neuroscience* 7, 3416-3468.

McLeod, P., Diver, J. & Crisp, J. (1988). Visual search for a conjunction of movement and form is parallel. *Nature* 332, 154-155.

Nakayama, K. & Silverman, G.H. (1986). Serial and parallel processing of visual feature conjunctions. *Nature* 320, 264-265.

Nelson, R., Famiglietti, E.V., Jr., & Kolb, H. (1978). Intracellular staining reveals different levels of stratification for ON- and OFF-center ganglion cells in the cat retina. *Journal of Neurophysiology* 41, 472-483.

Schiller, P.H. (1984). The connections of the retinal ON- and OFF- pathways on the lateral geniculate nucleus of the monkey. *Vision Research* 24, 923-932.

Treisman, A.M. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance* 8, 194-214.

Treisman, A.M. & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology* 12, 97-136.

Treisman, A.M. & Souther, J., (1985). Search asymmetry: A diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General* 114, 285-310.

Treisman, A.M. (1986) Features and objects in visual processing. *Scientific American* 255, 106-115.

Wässle, H., Peichl, L. & Boycott, B.B. (1983). A spatial analysis of on-and off-ganglion cells in the cat retina. *Vision Research* 23, 1151-1160.

Wolfe, J.M., Cave, K.R. & Franzel, S.L. (1989). Guided Search: An alternative to the Feature Integration model in visual search. *Journal of Experimental Psychology: Human Perception & Performance* 15, 419-433.

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