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Research Note

Localization and Discrimination of "Pop-out" Targets

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In parallel visual search, a target pattern "pops out" among distractors rapidly, requiring no effort, regardless of distractor numbers. The localization and discrimination of "pop-out" targets was investigated for this research note using similar multiple target displays to those used in Sagi and Julesz's [(1985a) *Science*, *228*, 1217–1219] and Folk and Egeth's [(1989) *Journal of Experimental Psychology: Human Perception & Performance*, *15*, 97–110] studies. The stimulus display contained 2, 5 or 10 oblique target line segments embedded in vertical distractor lines. In the first localization task, the observer indicated whether one of the oblique targets was in one of the two inside-corner positions of the display, or whether all the targets were in other positions. The second localization task was otherwise identical to the first one, except that the number of critical inside-corner positions was four. In the discrimination task, the observer reported whether all the target lines had the same orientation, or whether one of them differed in orientation from the others. Reaction times for correct responses were measured in all three tasks. The results showed that target discrimination took place in parallel, but target localization was a "serial" process, i.e. the localization time depended on the number of targets and critical locations to be checked.

Parallel vs serial search Localization vs discrimination

Several studies have shown that the search for a target pattern among distractor (non-target) patterns is fast and parallel (i.e. the search time is almost independent of the number of distractors in the display) when the difference between the target and distractors in some basic stimulus dimension is big enough (e.g. Nakayama & Silverman, 1986; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Verghese & Nakayama, 1994; Wolfe, 1992, 1994). For instance, when there is a large spatial frequency, colour or orientation difference between a target and distractors, the search takes place rapidly and in parallel: the target "pops out" among the distractors requiring no effort (e.g. Duncan, 1989; Verghese & Nakayama, 1994). As the target and distractors become more similar, the search occurs slowly, with effort and serially, i.e. the search time depends on the number of distractor patterns.

Recently, there has been some controversy over the visual information on which the pop-out phenomenon is based. Originally, Treisman and Gelade (1980) proposed that a pop-out target is identified prior to its localization, i.e. accurate spatial information about the location of a pop-out is not available at the early parallel stages of visual processing, when only the target identity has a representation.

Later, Sagi and Julesz (1985a, b) attacked this view and claimed that early visual mechanisms are in fact able to localize accurately a pop-out ("a discontinuity in a feature gradient"), but later attentive processing stages are required to identify the pop-out ("what the discontinuity in a feature gradient is"). In other words, the localization of a pop-out could be performed in parallel, whereas its identification should be a serial process. Sagi and Julesz's (1985a) claim was based on evidence coming from ingenious search experiments using multiple targets, i.e. the number of targets in a search display (not the number of distractors as is usual) was varied. The briefly flashed stimulus display consisted of short line segments so that the targets were horizontal and vertical lines among oblique distractor lines. In Sagi and Julesz's (1985a) localization task, the observer indicated the total number of targets irrespective of whether they were vertical or horizontal. In their identification task, the observer reported whether all the targets shared the same orientation, or whether one of them had a different orientation from the rest.

The results showed that performance was independent of the number of target line segments in the localization (rapid counting) task, but not in the task in which the observer discriminated between vertical and horizontal target lines. Because the observers localized targets in parallel and discriminated them serially, Sagi and Julesz (1985a) concluded that the localization of a pop-out takes place "preattentively" at the early vision

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whereas its identification requires the use of "focal attention".

Recently, several studies have extensively tested the notion that location information has a priority over identity information in the processing of visual pop-outs (e.g. Atkinson & Braddick, 1989; Folk & Egeth, 1989; for an excellent review of this topic see Green, 1992). For instance, Atkinson and Braddick (1989) and Green (1992) examined Sagi and Julesz's argument. They ran experiments in which the task of rapidly counting pop-out targets was not equated with that of pop-out localization, but the localization process was studied directly, i.e. the observer indicated the location of a pop-out among the distractors. These experiments, however, do not give an answer to the issue of parallel vs serial processing (localization and discrimination) of pop-outs because there was only one target pattern among the distractors.

In an interesting series of experiments, Folk and Egeth (1989) used similar multiple target displays of short line segments and an orientation difference between the targets and distractors, as in Sagi and Julesz's (1985a) study, in order to investigate the parallel vs serial discrimination of pop-outs (the study was not concerned with their localization). They were able partly to replicate Sagi and Julesz's results: the discrimination time lengthened when the target number increased from 2 to 4. However, when the display contained 6 targets, discrimination became faster.

Folk and Egeth (1989) also found some evidence suggesting that the discrimination of pop-out targets in fact occurs in parallel, and the increase in discrimination time with an increasing target number (up to 4 targets) may result from postperceptual processes. In that experiment, the observer looked for a single vertical or horizontal line segment among oblique distractor lines, and a variable number of *pseudotargets* which were line segments of orthogonal orientation to that of the actual target. Thus, it was not possible to detect the presence or absence of the target just by the orientation difference between the target and the oblique distractors, but the observer also had to discriminate between the actual target and any pseudotargets. The results of this experiment showed that the detection time was independent of the pseudotarget number, hence suggesting that the discrimination process itself (i.e. discrimination between the target and pseudotargets) would take place in parallel.

For this research note, the localization of pop-outs was investigated using multiple target displays consisting of short line segments. The display contained 2, 5 or 10 oblique targets embedded in vertical distractor lines. In the first localization task, the observer reported whether one of the oblique targets was in one of the two inside-corner positions of the search display. The second localization task was identical to the first one, except that there were now four critical inside-corner positions. These tasks were similar to Atkinson and Braddick's (1989) "fine localization". The aim of the experiments was to study whether accurate localization of pop-out targets can be performed in parallel, i.e. whether the localization time is independent of the target number as it was in Sagi and Julesz's (1985a) experiments.

A discrimination task was also run using similar stimulus displays: the observer indicated whether all the oblique targets among the vertical distractors had the same orientation (45° or 135°), or whether one of them differed in orientation from the rest (one of the targets had a 45° orientation and the other a 135° orientation, or vice versa). Reaction times for correct responses were measured in all three tasks.

METHODS

A MacintoshPlus computer and VScope software (Rensink, 1990) were used in running the experiments. The viewing distance was 50 cm and it was controlled by a chin rest. Both the target and distractor line segments were black on a white background, and the size of each line was 0.12×1.3 deg. The oblique targets and vertical distractors were placed randomly on an imaginary 5×9 grid (45 positions) subtending approximately 9×16 deg. There were no constraints for target positions, i.e. two targets could appear vertically, horizontally or diagonally adjacent. In order to prevent influences of line collinearity, there was random jitter in the positions of the vertical distractor lines. The oblique targets were present at every trial in all tasks.

In the two localization tasks, the stimulus display contained 2, 5 or 10 oblique targets (always at 135° orientation) embedded in 43, 40 or 35 vertical distractors, respectively. Hence, the total number of line segments in the display was constant (45) irrespective of the target number. The observer had to indicate whether one of the target line segments was in one of the critical inside-corner positions of the stimulus display (shown in Fig. 1), or whether all the targets were in other positions. In the first localization task, the number of critical positions was two, in the second it was four. Only one of the targets could be in one of the inside-corner locations at one time. The critical positions were equally probable. Half of the trials contained a target in the critical display positions, and in half all the targets were in non-critical locations.

In the discrimination task, there were 2, 5 or 10 oblique target lines (at 45° or 135° orientation) among 43, 40 or 35 vertical distractors, respectively. The observer reported whether the orientation of the oblique targets was identical (e.g. all at 45°) or whether one of them had a different orientation from the others (e.g. one 135° line and four 45° lines). In both the discrimination and localization tasks, the number of targets was randomly varied within a stimulus block.

A trial began with a warning tone after which a black 0.29×0.29 deg square appeared in the centre of the screen for 1 sec. The fixation point was immediately replaced by the stimulus line segments. After giving his response using a MacintoshPlus keyboard, the observer was provided with feedback. Response times of less than 200 msec were disregarded. All tasks were run in 5–6 blocks of 60–72 trials. The observers were instructed to respond as rapidly as possible, while minimizing errors. There were no signs of speed-error trade-off in their performance.

The two observers (JL and JS) had corrected-to-normal vision. JS was the author whereas JL was not aware of the purpose of the experiments. Both observers were well-practised in visual search experiments. There were several hundred preliminary trials prior to the final data collection phase.

RESULTS AND CONCLUSIONS

Figure 2 shows the response time plotted against the number of targets for the discrimination and localization tasks. The observers were able to perform the localization task rapidly and nearly independently of target number when there were only two critical inside-corner positions to be checked. However, when the number of critical positions was four, there was a significant increase in the response time with an increase in target number. The localization speed (the slope of the regression line fitted to the data) was approximately 10–15 msec/target in the first task, and 50 msec/target in

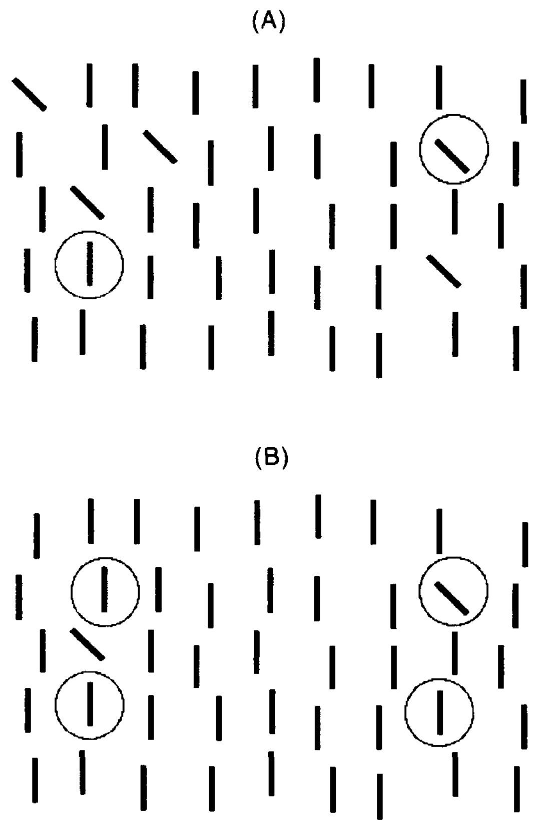

FIGURE 1. Illustrations of the stimulus displays used in the experiments. The display contained a variable number of oblique target line segments embedded in vertical distractor lines. In the first localization task (A), the observer indicated whether one of the oblique targets was in one of the two inside-corner positions of the array (marked with circles which were not present in the displays shown to the observer), or whether all the oblique lines were in other locations. The second localization task (B) was identical to the first one, except that the number of critical inside-corner positions was four. In both illustrations, one of the targets is in a critical position. The number of targets is five in the upper and two in the lower illustration.

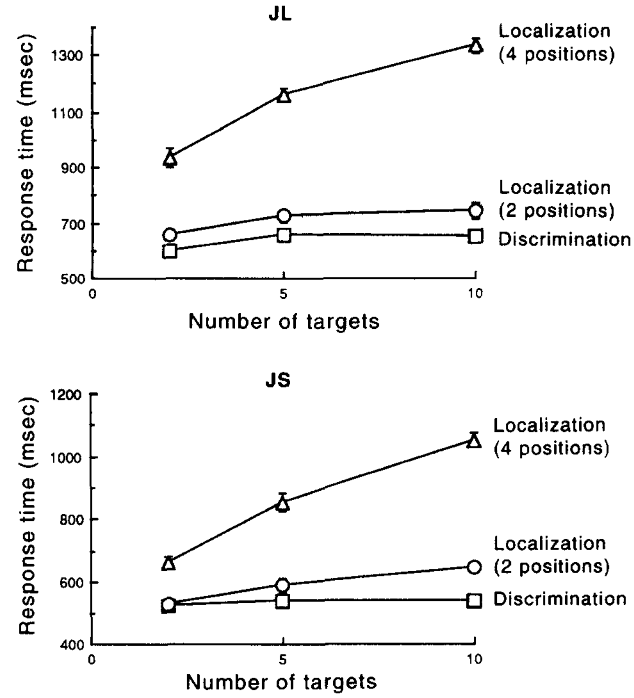

FIGURE 2. Response time as a function of the number of targets in the discrimination and localization tasks, separately for the two observers (JL and JS). The short vertical line segments show ± 1 SEM response time. For some data points, the SE is less than the size of the symbol.

the second task (Table 1). Thus, the accurate localization of pop-out targets can occur rapidly and almost in parallel, or slowly and serially, depending on the number of critical locations to be checked.

It has to be emphasized, however, that this result does not imply that the localization process *per se* requires the use of "focal attention", i.e. accurate location information would not emerge prior to the attentive stages of visual processing. Instead, the serial localization of pop-out targets in these experiments may just reflect the fact that it is not possible to "match" the prespecified critical locations of a stimulus display and the locations of pop-outs in parallel. In fact, experiments in texture perception (e.g. Nothdurft, 1993) show convincingly that pop-out information from multiple locations can be used in parallel for producing a global pattern shape.

The discrimination of oblique targets occurred rapidly and in parallel: the discrimination speed was 2–5 msec/target (Table 1). Just as in Folk and Egeth's (1989) results, there was a slight increase in the discrimination time as the target number increased from 2 to 5. At this point, it might be worth noting, however, that

TABLE 1. The slopes and standard errors of the regression lines (msec/target) fitted to the data in the discrimination and localization tasks

	Observer JL		Observer JS	
Task	Slope	SE	Slope	SE
Discrimination	5.3	2.6	1.9	2.7
Localization (2 positions)	10.5	4.1	14.8	2.9
Localization (4 positions)	48.6	5.6	47.7	4.6

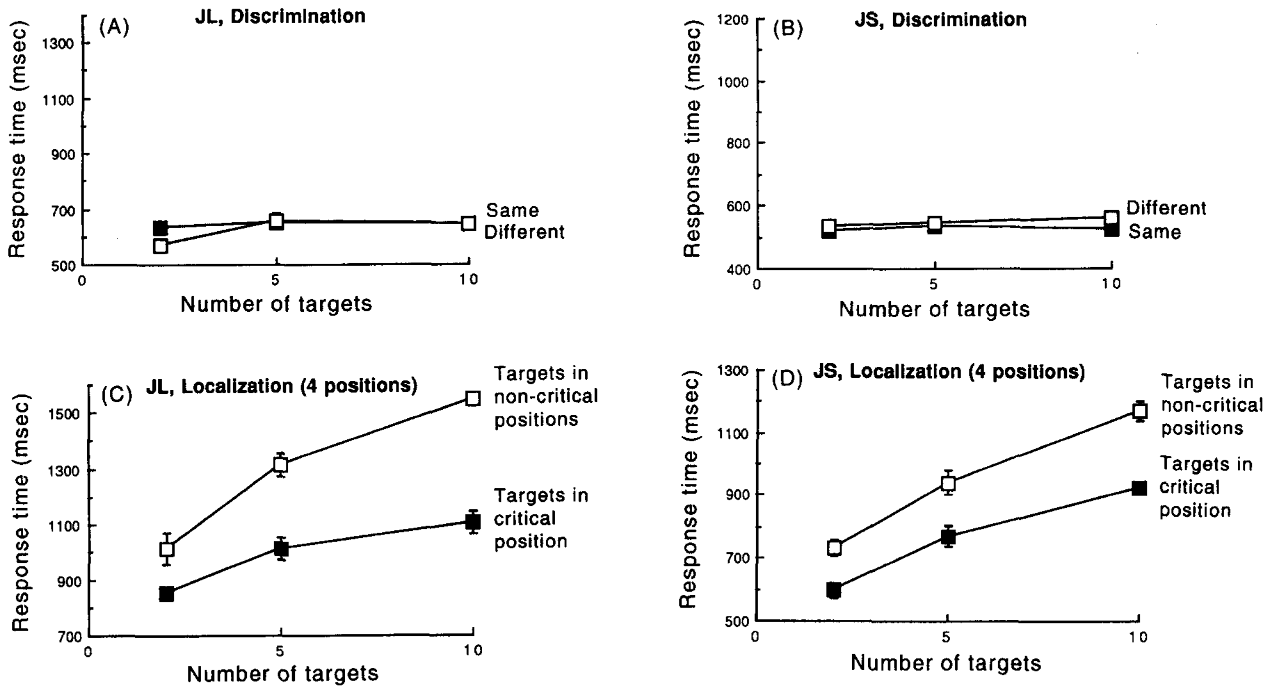

FIGURE 3. Reaction times in the discrimination and localization tasks plotted separately for "yes" and "no" responses. The vertical bars show ± 1 SEM response time. For some data points, the SE is less than the size of the symbol. In the localization task, the number of critical locations was four.

reaction time techniques may be less sensitive than accuracy measures in revealing serial processing, because in response time experiments the observer is not necessarily close to a performance limit (the proportion of correct responses is usually high), unlike in experiments using accuracy measures (cf. Verghese & Nakayama, 1994). Thus, dependency between target number and discrimination time might be "more serial" than was revealed by these reaction time experiments and those of Folk and Egeth (1989).

The linear increase of processing time with an increasing number of stimulus items is one way of diagnosing "serial" processing. Another is to compare reaction times for "target present" and "target absent" responses (e.g. Treisman & Gelade, 1980). Therefore, reaction times in the discrimination task and in the localization task with four critical inside-corner positions were plotted against target number, separately for "yes" and "no" responses (Fig. 3). In the discrimination task, a "same" response meant that all oblique targets had identical orientation and a "different" response referred to a stimulus condition in which one of the targets had a different orientation from the rest. Correspondingly, in the localization task, the observer responded "yes" when a target line was in a critical position, and "no" when all the targets were in non-critical positions.

Further analysis of the data showed that there were no differences between the reaction times for "same" and "different" responses in the discrimination task, but in the localization task, the response times for "no" were significantly longer than those for "yes". This also supports the notion that the localization of pop-outs (in the condition of four critical positions) is a serial and self-terminating process.

To summarize, these results seem to suggest that the issue of the priority of location information over identity information (or vice versa) may be somewhat ill-defined in current literature because the answer to this problem depends on what kind of tasks are chosen to represent "localization" and "identification".

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