PARTITIONING VISUAL DISPLAYS: DIRECTING THE PATH OF VISUAL SEARCH

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We reduced time to detect target symbols in mock radar screens by partitioning displays in accordance with task instructions. Targets appeared among distractor symbols either close to or far from the display center, and participants were instructed to find the target closest to the center. Search time increased with both number of distractors and distance of target from center, and the effect of distractors was considerably greater for far than close targets. However, when close and far regions were delineated by a centrally-presented "range ring", the distractor effect was substantially reduced, especially for far targets. We suggest that range rings focus attention on specific regions of the screen and aid in the determining of which regions have already been searched.

In real-world visual search tasks, processing goals often encourage observers to search displays in a specific pattern (e.g., "find the closest hospital to the bungey jump site"). Ideally, target locations would always be highlighted, cuing observers to attend precisely to important positions (e.g., Posner, Snyder, & Davidson, 1980). Still, although exact target locations cannot generally be cued in visual search (i.e., they are unknown), attending to different display regions in a pre-specified order in these "task-directed" visual searches should help to ensure that observers quickly detect targets in those locations in which it is most important to find them.

However, it is difficult to restrict attention within the confines of a small region in a visual display. Without a perceptual border delimiting the to-be-attended region, attention may actually spread to the entire visual hemifield in which the attended position is located (Hughes & Zimba, 1985). The processing of distractors within or near the focus of attention may be enhanced even if they have already been rejected, increasing interference with target detection (e.g., Eriksen and Eriksen,1974). Drawing in the boundaries of a to-be-attended region increases the extent to which display items can be included or excluded from the focus of attention in that region, modulating the effects of interference from distractors (Kramer & Jacobson, 1991). We reasoned that task-directed search may be facilitated by adding perceptual boundaries that define the regions that should be attended and ignored in turn.

We used such a technique to improve the efficiency with which observers searched for air track symbols within mock radar screens of the type presented in the Georgia Tech Aegis Simulation Program (GT-ASP) (Hodge, Rothrock, Kirlik, Walker, Fisk, Phipps, & Gay, 1995). A user operating GT-ASP is required to identify unknown aircraft before they fly within a 50 nautical mile (NM) range of the ownship, which is generally represented at the center of the display. All other track characteristics being equal, closer tracks are deemed to be more threatening than farther tracks; this encourages users first to ensure that targets are absent from regions close to the center before scanning regions farther away.

We were interested in how this inside-to-outside search process might be facilitated by the addition of a range ring, a centrally-presented circle that delineates the region contained within a certain range from the center of the scope (the position of the ownship). To evaluate its use, we conducted three inside-to-outside visual search studies using simplified versions of the GT-ASP radar screens. The radarscope was partitioned into "close" and "far" regions by a range ring with a radius half that of the full display. A target could appear within each region of the display, but participants were instructed to click on the one closer to the center. Importantly, the range ring was visible in the search displays in Experiments 2 and 3 only. In Experiment 2, the range ring appeared with the onset of the search symbols and was erased along with the search symbols as soon as participants clicked on the display. In contrast, the range ring remained on the screen the whole time in Experiment 3, allowing participants to use the range ring to focus attention prior to the onset of the search display.

We predicted that range ring would facilitate search by indicating the boundaries of to-be-processed and to-be-ignored regions, aiding in the precision with which observers could allocate attention to different portions of the display. We initially thought that these benefits might be especially strong when participants viewed the range ring prior to the onset of the search array (Experiment 3). However, we failed to find differences between Experiments 2 and 3, suggesting that use of the range ring required little preparation time.

GENERAL METHODS

Participants

A total of 45 undergraduates from Carnegie Mellon University participated in Experiments 1-3 for course credit ($\underline{N}$ = 15 for each experiment).

Apparatus

A Dell OptiPlex Gx1 computer was used to display stimuli and record responses. Stimuli were presented on an 16-inch monitor with a resolution of 640 x 480 pixels.

Stimuli and Experimental Design

A sample search display is shown in Figure 1 with its different components labeled. A large circle with a diameter of 19° of visual angle served as the outline of the radarscope (a). A small circle ($.48^{\circ}$ diameter) with a dot in its center served as the central fixation point (the ownship) (b). In Experiments 2 and 3, an additional circle with a diameter half that of the radarscope (9.5°) appeared centered around the fixation point, serving as the range ring that delineated "close" and "far" regions (c). Half-circle track symbols served as targets (d), while half-rectangle track symbols served as distractors (e) (each subtended an area of $.48^{\circ}$ x $.24^{\circ}$) Lines ($.72^{\circ}$) emanated from each track symbol at one of eight orientations (in a full-scale GTASP experiment, these serve to indicate speed and course). The mouse arrow that participants positioned over target symbols measured approximately $.95^{\circ}$ x $.48^{\circ}$.

There were two target conditions: **close target** and **far target**. In close target displays, one target appeared in the close region and one target appeared in the far region; in far target displays, one target appeared in the far region only. Targets appeared in each quadrant an equal number of times in each condition.

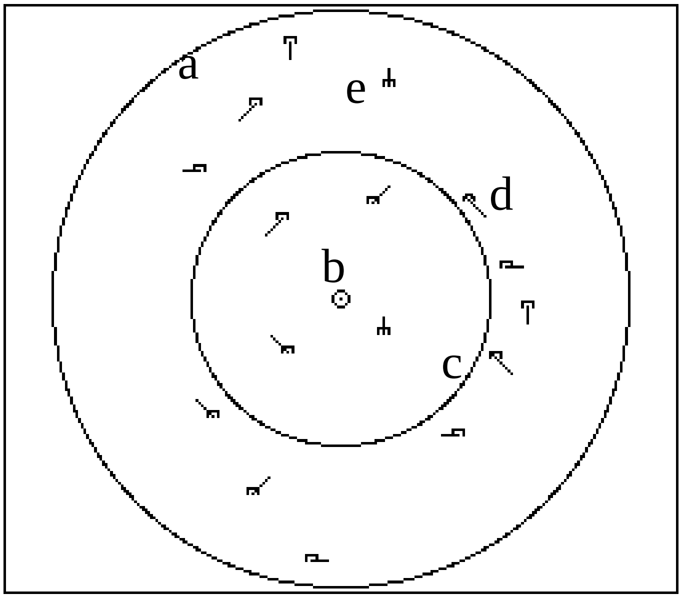

Figure 1: Sample display with range ring

The two target conditions were crossed with three distractor conditions: **no distractors**, **low distractors**, and **high distractors**. No distractors appeared in the no distractors condition. In the low distractors condition, close target displays contained three distractors in the close region and three distractors in the far region, while far target displays contained four distractors in the close region and three distractors in the far region (thus, every display contained a total of eight symbols). Finally, in the high distractors condition, both close and far target displays contained an additional four distractors in the far region only. For both low and high distractor displays, additional symbols were distributed equally among all four quadrants.

Distractors were added only to the far region in the high distractors condition in order to permit an assessment of the extent to which peripheral distractors interfered with the processing of targets appearing in the close region. If the addition of distractors to the far region created minimal interference, then this would indicate that participants effectively restricted their attention to the close region at the start of the search process.

A total of 64 displays were generated for each of the six conditions created by the crossing of target x distractor conditions. The low distractor displays were created by adding distractors to the no distractor displays. Similarly, the high distractor displays were created by adding additional distractors to the low distractor displays. Displays were identical for all experiments, excepting that they contained the range ring in Experiments 2-3.

Procedure

Participants viewed displays from a distance of approximately 60 cm. The radarscope outline was always present in the center of the monitor throughout the course of the experiment (i.e., it was not erased between trials). During Experiment 3, the range ring also remained present throughout the course of the experiment. To begin a trial, participants clicked the fixation symbol with the mouse arrow. Target and distractor symbols appeared 300 msec later (along with the range ring in Experiment 2). Participants were instructed to click on the target symbol closest to the center as quickly and accurately as they could. Each trial ended as soon as the mouse was clicked, at which point target and distractor symbols were erased (along with the range ring in Experiment 2).

RESULTS AND DISCUSSION

Error Analyses

Any click within 10 pixels of the target symbol (a region subtending 1.91° x 1.43°) was scored as correct. Close target trials were separated into "wrong target" errors (in which participants clicked on the far target instead of the close target) and "other" errors.

The simple effect of distractor number (no distractors vs low distractors vs high distractors) was significant for close wrong target errors in Experiment 1 [0.31% vs 1.46% vs 1.88%; F(2,28) = 6.048, MSE = .000162, p = .007] and Experiment 2 [0.42% vs 2.29% vs 1.25%; F(2,28) = 6.035, MSE = .000219, p = .007]. This pattern of errors suggests that participants were more likely to miss the close target when displays contained distractors, indicating that distractors were effective at interfering with target detection even in the close region. All other effects were non-significant.

Reaction Time Analyses

For each participant, mean reaction time (RT) scores for correct trials were calculated for each of the six conditions. From these values, mean RTs for each condition in each experiment were then determined. To eliminate outlying data points, those trials with RTs more than two standard deviations above or below the experiment's condition mean were removed from analysis (an average of 4% of the trials in each condition). Condition means were then recalculated for each experiment. These are displayed in Figure 2a (close targets) and 2b (far targets).

As is evident in Figure 2ab, the effect of distractors was much greater for far than close targets (note the y-axis scale difference) as indicated by the interaction of target location (close vs far) and distractor number (no distractors vs low distractors vs high distractors) [Experiment 1: F(2,28) = 248.38, MSE = 26927.20, p < .0005; Experiment 2: F(2,28) = 237.14, MSE = 11776.73, p < .0005; Experiment 3: F(2,28) = 187.94, MSE = 13875.60, p < .0005]. This difference reflects a combination of factors, including decreasing visual acuity with greater distance from fixation, increased masking from peripheral distractors, mouse movement time, and scanning pattern (i.e., searching the display from the inside to the outside). As a result, close and far target conditions were analyzed separately.

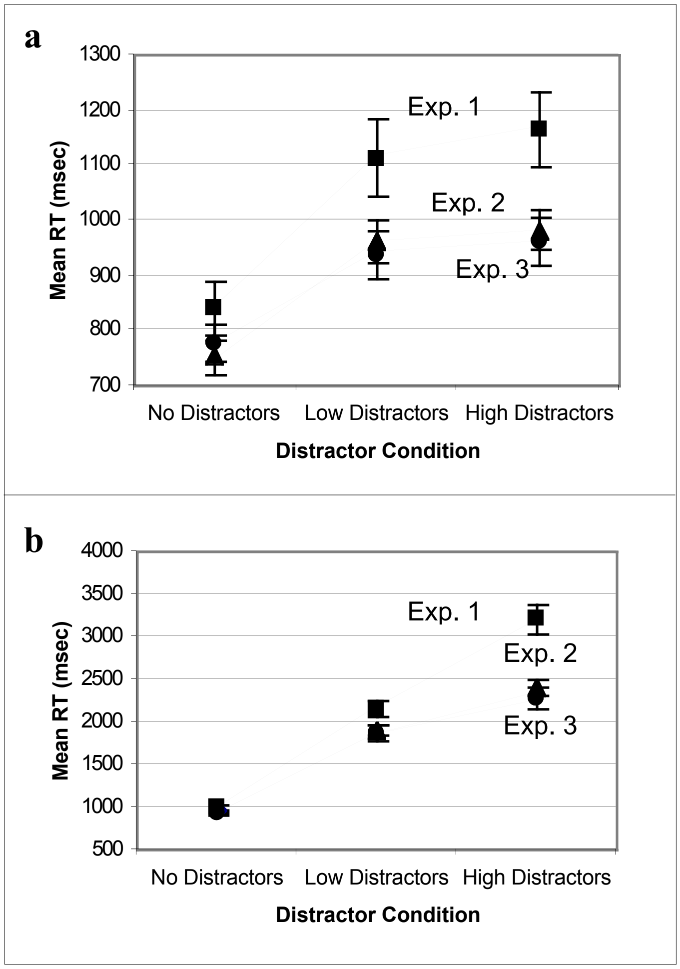

Figure 2: (a) RT results for close targets (b) RT results for far targets

Close target results. There was a main effect of distractor number in all three experiments [Experiment 1: F(2,28) = 91.218, MSE = 5031.15, p < .0005; Experiment 2: F(2,28) = 150.73, MSE = 1630.05, p < .0005; Experiment 3: F(2,28) = 92.147, MSE = 1637.62, p < .0005]. This indicates a general increase in RT as distractor number increased. However, although the RT increase between low and high distractor conditions was significant or marginally significant in all experiments [Experiment 1: t(14) = 3.26, p = .006; Experiment 2: t(14) = 2.10, p = .055; Experiment 3: t(14) = 3.20, p = .006], the increase between no and low distractor conditions was much greater [(low – no) vs (high – low) for Experiment 1: t(14) = 5.83, p < .0005; Experiment 2: t(14) = 7.52, p < .0005; Experiment 3: t(14) = 8.02, p < .0005].

The relatively minor influence of the additional far distractors in the high distractor conditions suggests that the greatest source of interference for close target detection came from distractors in the close region. This, along with the dramatic differences in RTs between trials with close and far targets, suggests that participants did begin their searches in the close region of the display and were fairly successful at filtering out distractors appearing in the periphery.

The increase in RT between low and high distractor conditions may reflect the capturing of attention by distractors appearing in locations in the far region that lay near to the close/far boundary; that is, the span of attention might have “spilled over” the division even when the boundary was delineated by the range ring. Additional far distractors in the high distractor condition might have increased the difficulty of figure/ground separation for the range ring, as well, increasing the time required to discern it from the field of distractors. However, given the size of this effect and considering the entire pattern of results in these experiments, it is unlikely that it represents instances of scanning from the outside in.

Note that the high-low RT difference was greatest in the no range ring condition (Experiment 1); although non-significant, this trend suggests that “attention spill-over” may have been reduced when the range ring was present as a focusing guide. Indeed, the range ring did effectively reduce the effect of distractors. Comparisons between no distractor conditions and high distractor conditions illustrate this point: There were no differences between the RTs for no distractor conditions, but high distractor RTs were lower in both Experiment 2 [t(28) = 2.416, p = .022] and Experiment 3 [t(28) = 2.531, p = .017]. This difference may be attributed to more effective filtering of peripheral distractors and enhanced processing of symbols in the close region.

Far target results. There was a main effect of distractor number in all three experiments [Experiment 1: F(2,28) = 265.30, MSE = 69334.71, p < .0005; Experiment 2: F(2,28) = 266.29, MSE = 30264.37 , p < .0005; Experiment 3: F(2,28) = 178.96, MSE = 39634.14, p < .0005]. This reflects the large increase in RT with increasing distractors. The RT increase between low and high distractor conditions was significant in all experiments, indicating that the additional far distractors interfered further with target detection [Experiment 1: $t(14) = 13.20$, $p < .0005$; Experiment 2: $t(14) = 9.54$, $p < .0005$; Experiment 3: $t(14) = 12.14$, $p < .0005$]. Moreover, the high-low distractor RT difference was no smaller than the low-no distractor RT difference in Experiment 1 [$t(14) = 1.718$, $p = .108$].

However, the high-low distractor difference was significantly smaller than the low – no distractor RT difference for Experiments 2 and 3 [Experiment 2: $t(14) = 9.37$, $p < .0005$; Experiment 3: $t(14) = 11.57$, $p < .0005$]. Moreover, the difference between low-no and high-low was significantly smaller in Experiment 1 than in either Experiment 2 or 3 [Experiment 1 vs Experiment 2: $t(28) = 3.78$, $p = .001$; Experiment 1 vs Experiment 3: $t(28) = 4.27$, $p < .0005$]. These results indicate that the addition of distractors to the far region had less of an effect on target detection when displays contained the range ring. While search time essentially doubled from low to high distractor conditions in Experiment 1, there was much less of an increase in Experiments 2 and 3. Thus, the benefits of the range ring for far target detection increased as the number of distractors increased.

GENERAL DISCUSSION

Experiments 1-3 demonstrated that partitioning displays into task-relevant regions with a range ring facilitated inside-to-outside search. We suggest that the range ring helped observers to allocate attention to different positions within the display with more precision, facilitating both the processing of symbols within the attended region and also the filtering out of peripheral distraction.

The greater effect of the range ring for far rather than close targets suggests that displaying the close/far boundary did far more than simply focusing attention on the close region at the start of the trial; we propose that it directed the path of scanning throughout the course of the search. There is evidence that observers find it difficult to follow a prescribed path of saccades through dense arrays of symbols (Hooge & Erkelens, 1998). There is also evidence that observers have an imperfect memory for the distractors they have recently rejected in the course of search (Horowitz & Wolfe, 2001). Participants could use the range ring as a landmark around which to focus attention more effectively (first attending to the close region, then sweeping around the far region). This would limit repeated analysis of distractors resulting either from forgetting which distractors had already been searched or focusing attention too imprecisely over a display region that included rejected distractors.

Displays with a greater separation between symbols and a simpler stimulus configuration (e.g., symbols arranged in a circle) should be easier to scan and may not benefit from the addition of perceptual boundaries. Moreover, search paradigms that do not encourage task-directed scan-paths may actually be hurt by partitioning. Partitioning encourages organized scanning along the perceptually-designated path, and constraining the path of search may limit the effectiveness with which attention is attracted to salient target features in the display (Wolfe, Alvarez & Horowitz, 2000). However, to the extent that additional perceptual landmarks reduce accidental reprocessing of distractors, partitioning may aid even a random search through some complex displays. Resolution of this issue is a matter for future study.

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