EFFECTS OF NOISY DISTRACTORS AND STIMULUS REDUNDANCY ON VISUAL SEARCH

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In a visual search task, subjects detected the presence of a target (long vertical line) among distractors that differed in length, orientation, or both. Distractors were designed to model the random variability found in naturalistic data by having them vary normally around the mean distractor. As predicted, adding variability to distractors eliminated popout by increasing reaction times and search function slopes, but redundant coding on two dimensions reduced search times and restored the popout effect.

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Effects of Noisy Distractors and Stimulus Redundancy on Visual Search

Studies using visual search tasks have shown that certain qualitatively distinct stimuli (traditionally called "textons"; Julesz & Bergen, 1983) will "pop out" from a briefly presented array of distractor stimuli regardless of the number of distractors in the display. Although such high levels of preattentive discriminability have usually been attributed solely to differences between the target and distractor stimuli, Duncan and Humphreys (1989) recently proposed that the ease of search tasks depends jointly on target-nontarget differences and the degree of homogeneity within the class of distractors. In this formulation, popout depends on the ratio of the target-nontarget difference to the level of variability among nontargets, a notion that bears interesting similarities to signal detection theory.

Because visual search studies have usually employed qualitatively distinct stimuli (e.g., letters, colors), few studies in this area have directly manipulated quantitative stimulus dimensions in a way that would allow Duncan and Humphreys's (1989) notions of target-nontarget difference and distractor similarity to be quantified. In the present experiment, we manipulated target-distractor differences and distractor variability by defining stimuli in such as way that their differences could be quantified in units of variability (standard deviations). This was done by drawing distractors from populations with known means and standard deviations along the dimensions of length and orientation. Such a procedure has two potential advantages: (1) It permits the quantification of stimulus differences in familiar psychophysical terms of variability units (as in signal detection theory), and (2) it allows visual search tasks to model the use of textural elements in scientific visualizations of real-world data (e.g., Healey, Booth, & Enns, 1996), where data are coded as textural features, but naturally occurring variability in the data may reduce the detectability of the effects that the displays are designed to make visible.

Method

Displays, presented on a Silicon Graphics Indigo2 computer with anti-aliasing software, subtended 11 x 11 degrees of visual angle at a viewing distance of 52 cm, with the target subtending 1 degree. The target appeared on a random half of trials and the number of distractors was either 1, 5, or 11 within a session. Subjects pressed the left and right shift keys to report target absence or target presence.

Six well-practiced subjects searched displays for a long vertical line (24 pixels in length) among distractors that, in separate conditions, differed in length, orientation or both. The mean distractor was a vertical line 12 pixels in length (in the length condition), a line 24 pixels long at a 45-degree orientation (in the angle condition), or a line 12 pixels long at 45 degrees (in the combined condition). However, distractors could also vary in length and orientation according to normal distributions. Under three conditions of variability, the standard deviations of these distributions were:

variability	length (pixels)	angle (degrees)
zero	0	0
medium	1.5	7.5
high	3	15

The exact length and/or orientation of each distractor was determined by multiplying the appropriate SD for the condition by a random normal deviate (Box & Muller, 1958). Note that, with this arrangement, the mean target-nontarget difference can be quantified (in signal detection fashion) as a difference of 4 SDs for the length task and 3 SDs for the orientation task in the high-variability condition, and as 8 SDs of length and 6 SDs of orientation in the medium-variability condition (for other treatments of visual search in signal detection terms, see Chun & Wolfe, 1996, and Swensson & Judy, 1981).

Six well-practiced observers served as subjects. Each subject ran for 27 sessions of 40 displays each, with each session representing one of the possible combinations of set size, variability, and stimulus dimension. This resulted in a 3 (set size) x 3 (variability) x 3 (dimension) design. Reaction times and errors (which averaged 4% and were less than 10% in all conditions) were recorded by the computer.

Results and Discussion

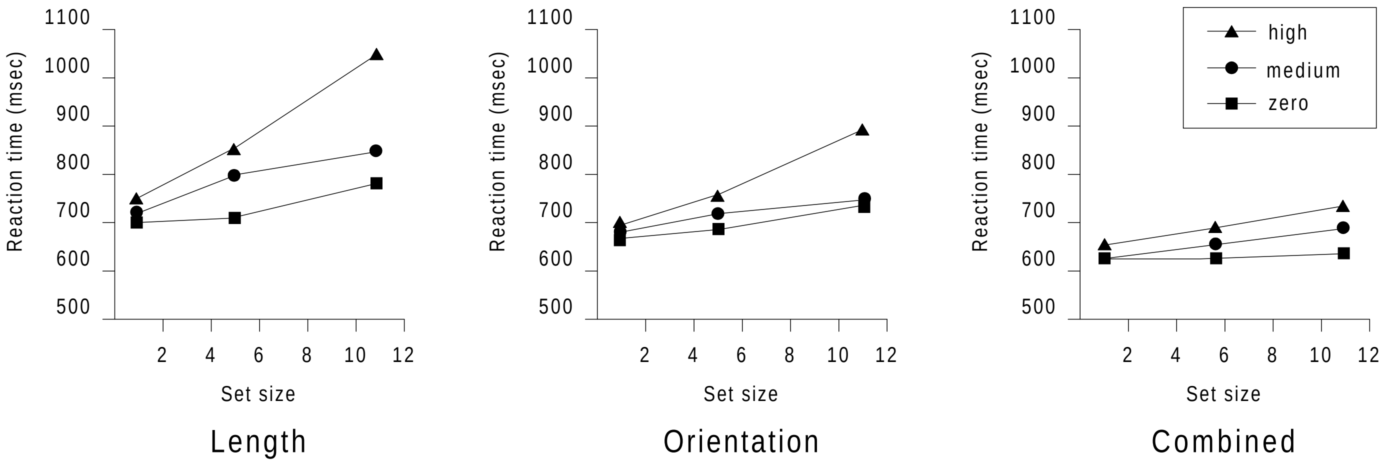
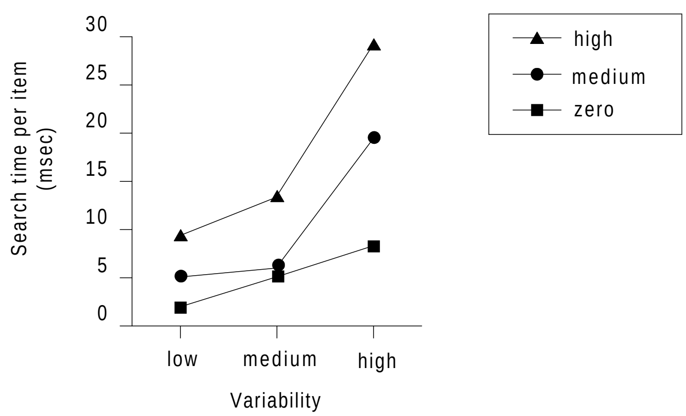


Figure 1

Figure 1 shows the mean reaction times as a function of set size for the three stimulus-dimension conditions. The search functions for the zero-variability conditions were essentially flat (under 10 msec/item in all cases), indicating that popout occurred in all three conditions when the distractors were fixed (i.e., zero variability), as in traditional visual search tasks. However, the search functions for the conditions of medium and high variability indicate that adding random noise to distractors increased reaction times, and did so in proportion to the amount of variability added. A repeated-measures ANOVA on reaction time revealed a significant main effect for variability, $F(2,10) = 103.4$, $p < .05$, and planned contrasts showed that all three variability conditions differed from each other, $ps < .05$. The ANOVA also revealed a main effect for stimulus dimension, $F(2,10) = 18.75$, $p < .05$, with contrasts showing that reactions times were lowest for the combined dimension in all three variability conditions ($ps < .05$). In addition, there was a significant Dimension X Variability interaction, $F(4,20) = 4.17$, $p < .05$, indicating that the effects of variability depended on the stimulus dimension.

The dependence of the effects of variability on the stimulus dimension was further explored by performing a separate repeated-measures ANOVA on the slopes of the search functions. As with the reaction times, the slopes were significantly affected by both the stimulus dimension and the level of variability in the distractors (ps for both main effects less than .05). Moreover, planned contrasts showed that the slope for the combined dimension in the high variability condition was significantly lower than for either length or orientation alone (ps < .05). Along with the finding of shorter reaction times in the combined condition, this result suggests that redundancy in stimuli can produce perceptual additivity even in preattentive visual search tasks, and thus help to restore visual popout even among noisy stimuli. This point is reinforced by inspection of Figure 2, which shows the slopes of the search functions as a function of variability and dimension. Although the slopes increase monotonically with variability for all three dimensions, those for the combined condition remain below 10msec/item (the usual criterion for visual popout) even with high-variability distractors.



Slopes (search time per item)

Figure2

Three conclusions may be drawn from the present study, First, a signal detection approach to quantifying visual search stimuli in terms of variability units provides a viable means for testing the claim of Duncan and Humphreys (1989) that popout depends both on target-nontarget differences and on the homogeneity of the nontargets. The present results clearly support Duncan and Humphreys's theory. Second, the present results cast doubt on earlier theories of visual search (e.g., Julesz & Bergen, 1983) in which the "textons" supporting popout were said to be visual primitives (including line length and orientation) that could not combine or interact during preattentive visual processing. Our finding that visual search was facilitated by stimulus redundancy counters this notion, as does much other recent work (e.g., Enns & Rensink, 1990).

Finally, the present study has implications for the use of textural elements in scientific visualizations. Line length and orientation have been used in visualizations of such natural phenomena as wind flow and salmon migrations, for example by coding direction of movement as orientation and speed as length. One common problem with these visualization techniques is that the random variability occurring in naturalistic data can prevent the easy detection of patterns in the data by impeding the visual segmentation of textures that is required for pattern detection. However, in cases of multivariate displays where correlated variables are coded as textural features (as when wind direction and speed are correlated), the desired pattern recognition may be retained in the face of noisy data by virtue of redundancy in the data dimensions.

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