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Saccadic selectivity during visual search: The effects of shape and stimulus familiarity

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Abstract

Three experiments were designed to examine the influence of shape feature and stimulus familiarity on saccadic selectivity during visual search. Robust shape feature based guidance was found in Experiment 1. In contrast, familiarity-based guidance was much smaller in magnitude and was observed with an unfamiliar target (Experiments 2 & 3) but not with a familiar target (Experiments 1, 2 & 3). Results from the current study suggest that there are qualitative and quantitative differences between the saccadic selectivity produced by stimulus familiarity and that produced by low-level features.

The Guided Search Model proposed by Wolfe, Cave and Franzel (1989) and Wolfe (1994) argues that information extracted preattentively could guide the shifts of attention during visual search. One potential prediction from this theory is that if a particular feature or stimulus dimension guides visual search, distractors which share that feature or dimension with the target will be fixated on more often than those distractors which do not. Studies monitoring eye movements have produced ample evidence that is consistent with this prediction. Stimulus dimensions such as color, orientation, shape and size (e.g., Findlay, 1997; Motter & Belky, 1998; Williams, 1967; Williams & Reingold, 1999; but see Zelinsky, 1996) have been shown to bias the distribution of the saccadic endpoints.

The current study examined whether participants could use learned stimulus properties, such as the familiarity of the stimuli, to guide eye movements during the search process. Stimulus familiarity has been shown to strongly influence visual search efficiency in several studies (e.g., Frith, 1974; Krueger, 1984; Reicher, Snyder & Richards, 1976). Wang, Cavanagh and Green (1994) further claimed that stimulus familiarity behaves like a primitive feature that could be processed preattentively. If this were the case, stimulus familiarity should bias saccadic endpoints in a manner similar to low-level features such as color and shape. In the current study, three experiments were conducted to examine whether stimulus familiarity could produce saccadic selectivity during visual search.

General Method

The eyetracker employed in this research was the SR Research Ltd. EyeLink system. This system has high spatial resolution (0.005°), and a sampling rate of 250 Hz (4 ms temporal resolution). By default, only the subject's dominant eye was tracked in our studies. In the present study, the configurable acceleration and velocity thresholds were set to detect saccades of 0.5° or greater.

Stimulus displays were presented on two monitors, one for the participant (a 17-inch Viewsonic 17PS) and one for the experimenter. The experimenter monitor was used to give feedback in real-time about the participant's computed gaze position. In general, the average error in the computation of gaze position was less than 0.5° of visual angle.

Participants were presented with a number of visual search displays. At the beginning of each trial, a fixation dot was displayed in the center of the computer screen in order to correct for drift in gaze position. Participants were asked to fixate on the dot and then press a start button to initiate a search display in the center of the screen. They were asked to decide quickly and accurately whether the target was in the display or not. The trial terminated if parti-

Table 1: Search targets and Distractors used in the current study

Experiment	Targets	Familiar Distractors	Unfamiliar Distractors
Expt 1	P F	B D E T	ꓭ ᗡ Ǝ ⊥
Expt2	A ∀	F N Y	Ⅎ ⅄ ᴎ
Expt 3 (Group 1)	OF ꟻO	GO TO OK OR	Oᘓ Oꓕ ꓘO ᴙO
Expt 3 (Group 2)	FIT TIꟻ	TIN TIP SIT BIT	ᴎIT ꟼIT TIƧ TIꓭ

cipants pressed one of the response buttons or if no response was made within 20 seconds. The particular buttons used to indicate target presence or absence were counterbalanced across participants.

Experiment 1

The goal of the first experiment was to examine whether shape feature and stimulus familiarity would produce saccadic selectivity. Two different search targets were used in the current experiment: **P**, which has curvature and closure, and **F**, which does not. Eight distractors (**B**, **D**, **E**, **T** and their 180° degree rotated form) were used (see Table 1). These distractors could be categorized into four groups: familiar distractors with curvature and closure (**B** and **D**); familiar distractors without curvature or closure (**E** and **T**); unfamiliar distractors with curvature and closure (rotated **B** and **D**) and unfamiliar distractors without curvature or closure (rotated **E** and **T**). All stimuli subtended 1.6 degree vertically and 1.3 degree horizontally. Displays consisted of 24 stimuli and were created using an imaginary 6 × 6 grid of stimulus positions, which subtends 12 × 12 degrees (see Figure 1 for an example).

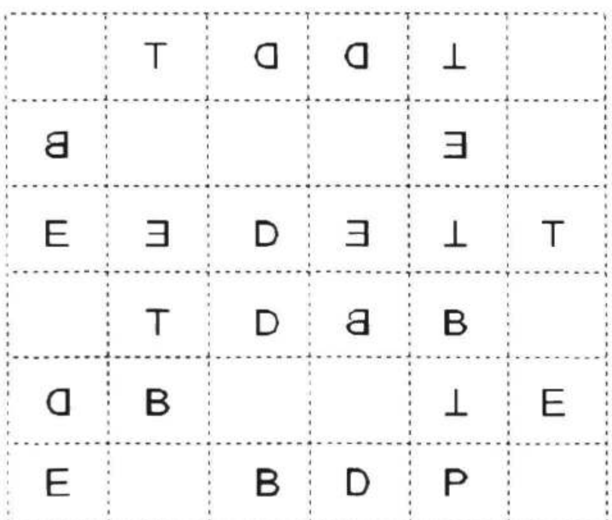

Figure 1: A sample search display used in Experiment 1 (target was a **P**). The dotted grid was not shown to the participants.

Twelve participants were tested individually in a single one-hour session. Each participant received six blocks of 96 trials (three blocks for **F** and three blocks for **P**). At the beginning of the experiment, participants received two practice blocks of 18 trials, one for each search target. Each participant searched both targets with the order of target presentation counterbalanced across individuals.

Trials in which participants responded incorrectly were excluded from analysis (3.4% of all test trials). Following Zelinsky (1996), only target-absent trials were included in the current analysis. The fixations were assigned to the nearest distractors and then proportions of fixations to each type (similar vs. dissimilar feature) were calculated. When **F** was the search target, participants made 56.0 % fixations to those distractors without curvature and closure (**E**, **T**, and rotated **E** and **T**) and 44.0 % fixations to the distractors with curvature and closure (**B**, **D**, and rotated **B** and **D**). Similarly, when **P** was the search target, 58.1% of the fixations were directed to the distractors with curvature and closure whereas 41.9% fixations to were directed to the distractors without curvature and closure. The overall shape-based guidance, calculated by subtracting the proportion of fixations made to the distractors with dissimilar shape-feature from the proportion of fixations made to the distractors with similar shape-feature, was 14.1%, t (11) = 7.75, $p < .01$. This effect was quite robust and observed across all 12 participants and across saccades of different amplitude (see Figure 2). The magnitude of the saccadic guidance, however, was stronger for the saccades within 2 degrees than for those above 6 degrees. In addition, the guidance for **P** was slightly stronger than that for **F** (16.2% vs. 12.0%, t (11) = 2.2, $p < .05$).

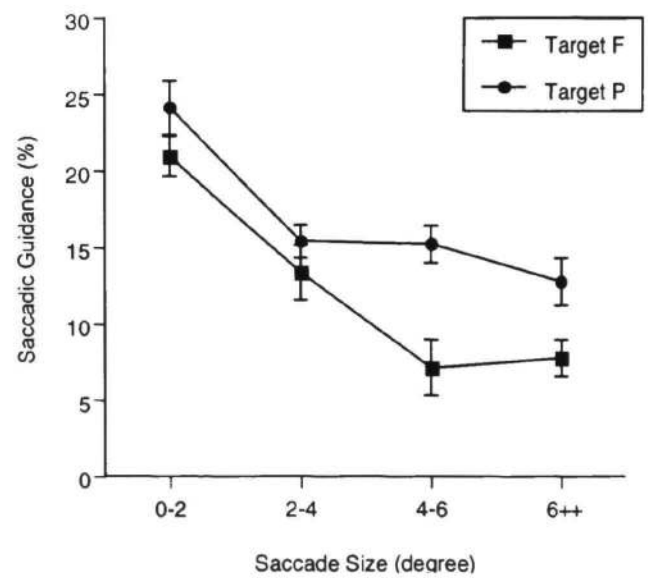

Figure 2: Percentage of saccadic guidance as a function of preceding saccadic amplitude. Saccadic guidance was calculated as the difference in the proportion of saccades between the similar and different shape-feature distractors.

Following the same procedure, proportions of fixations to the familiar versus unfamiliar distractors were calculated. Participants were equally likely to make fixations to the familiar and unfamiliar distractors (49.8% to the familiar distractors vs. 50.2% to the unfamiliar distractors). Thus, in the present experiment, when a familiar target was used, there was no significant guidance by familiarity (the difference was – 0.4 %, $t < 1$).

Experiment 2

To examine the generality of the findings from Experiment 1, this experiment employed a more powerful manipulation of the stimulus familiarity. In addition, both familiar and unfamiliar targets were included.

The search targets used in the current experiment were **A** and **Ʌ̄**, which was derived by moving the middle bar of **A** to the top. The familiar distractors were **F**, **N** and **Y** whereas the unfamiliar distractors were formed by recombining the same set of features from the familiar distractors (Reingold & Jolicoeur, 1993; see Table 1). All stimuli subtended 1.6 degree vertically and 1.3 degree horizontally. Similar display composition as in the previous experiment was used except that the display size was kept at 18 (see Figure 3 for an example). Each of twelve participants received 6 blocks of 96 trials preceded by two blocks of 24 practice trials representing each search target.

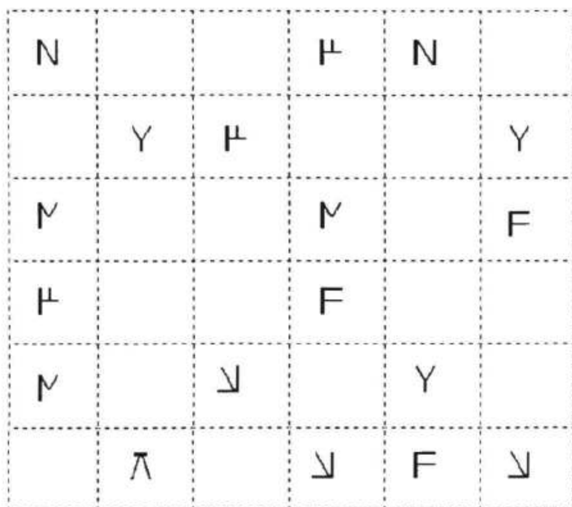

Figure 3: A sample search display used in Experiment 2 (Search target was a **Ʌ̄**). The dotted grid was not shown to the participants.

Similar to the previous experiment, fixations were assigned to the nearest distractors. For both the familiar and unfamiliar target, proportions of fixations made to the familiar versus unfamiliar distractors were calculated. When participants were searching for a familiar target, there was no difference in the distribution of fixations between the familiar and unfamiliar distractors (48.3 % of the fixations to the familiar distractors vs. 51.7 % to the unfamiliar distractors; the difference was – 3.4%, $t\ (11) = 1.75$, $p > .05$). In marked contrast, when the target was unfamiliar, more fixations were made to the unfamiliar distractors than to the familiar ones (45.4 % to the familiar distractors vs. 54.6% to the unfamiliar distractors; the difference was about 9.2 %, $t\ (11) = 8.01$, $p < .01$). This effect was observed when the size of the preceding saccade was within 6 degrees but disappeared at larger amplitudes (see Figure 4).

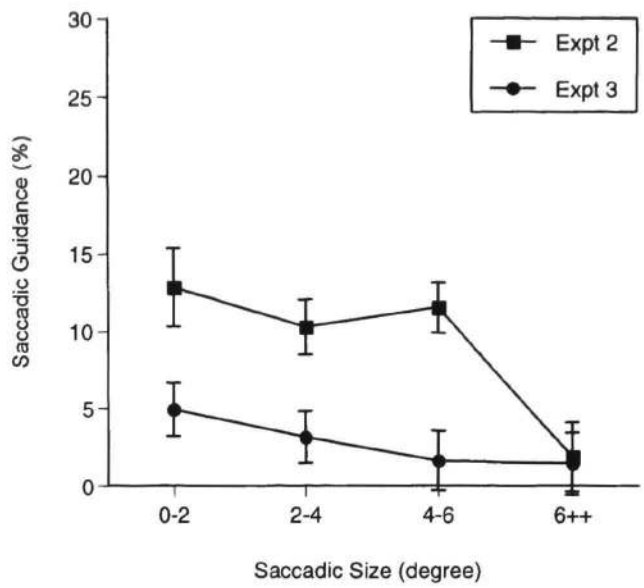

Figure 4: Percentage of saccadic guidance as a function of preceding saccadic amplitude (degree) for the unfamiliar target in Experiment 2 (in square) and 3 (in circle). Saccadic guidance was calculated as the difference in the proportion of saccades between the familiar and unfamiliar distractors.

Experiment 3

This experiment was designed to replicate the findings from Experiment 2, with words used as familiar stimuli and rotated or reflected words as unfamiliar stimuli. Two groups of six participants were tested. For one group, the targets were **OF** and its 180° rotation whereas the distractors were **GO**, **TO**, **OK** and **OR**, and their 180° rotated forms. Each stimulus subtended 1.3 degree vertically and 1.6 degree horizontally. For the other group, the targets were **FIT** and its left-right reflection, with distractors being **TIN**, **TIP**, **SIT** and **BIT**, and their left-right reflection (see Table 1). Each stimulus subtended 1.1 degree vertically and 1.6 degree horizontally. For both groups, the display size was fixed at 16. Each of 12 participants received six blocks of 96 test trials with two practice blocks of 24 trials, representing each of the search targets.

The results from both groups were identical and thus were reported together. Just as in previous two experiments, there was no guidance with a familiar target (49.5 % of the fixations made to the familiar distractors vs. 50.5% to the unfamiliar distractors; the difference was -1.0%, $t\ (11) < 1$). When the search target was unfamiliar, participants made more fixations to the unfamiliar distractors than to the familiar distractors (51.6% vs. 48.4%; the difference was 3.2%, $t\ (11) = 3.43$, $p < .01$). This effect was much smaller than that observed in the previous experiment (9.1%) and was evident only when the preceding saccade size was below 4 degrees (See Figure 4).

General Discussion

The current study examined whether shape feature (curvature and closure) and stimulus familiarity could guide visual search effectively. Results from Experiment 1 revealed a robust shape feature based guidance. Both the presence and the absence of the shape feature (curvature and closure) biased saccadic endpoints, though stronger bias was observed for the presence of the curvature and closure. Furthermore, the shaped-based saccadic selectivity was observed across all saccadic amplitude. Thus, the current study provided further evidence for guidance by low-level features during visual search (e.g., Findlay, 1997; Motter & Belky. 1998; Williams, 1967; Williams & Reingold, 1999; but see Zelinsky, 1996).

Another finding from the current study is that stimulus familiarity biased saccadic endpoints in a different manner than the shape feature. Across all three experiments, when a familiar search target was involved, there was no bias in the distribution of saccadic endpoints. In Experiments 2 and 3, a small but consistent familiarity-based guidance was observed with an unfamiliar target. The familiarity-based saccadic selectivity was only observed when the preceding saccade was small in amplitude (no more than 6 degrees).

Why was saccadic selectivity only observed with an unfamiliar target but not with a familiar target? There are many potential differences between searching for a familiar versus an unfamiliar target. Such differences may include the nature of target representation as well as comparison processing efficiency (Reingold & Jolicoeur, 1993). Therefore, a strong interpretation of the current data is premature. Nevertheless, one possible explanation can be based on the interaction of the bottom-up activation and top-down activations as postulated by the guided search theory (Wolfe, 1994; Wolfe et. al., 1989). It has been speculated that the unfamiliar stimuli elicit more activity and constitute larger bottom-up activation during the search process (Treisman & Gormican, 1988; Wang et. al., 1994). When an unfamiliar item is specified as the search target, both the bottom-up activation and top-down activation guide attention towards the unfamiliar distractors. Accordingly, participants tend to direct more saccades towards the unfamiliar distractors. On the other hand, when a familiar item is designated as the search target, the goal-directed top-down activation guides attention towards the familiar distractors whereas the bottom-up activation guides attention towards the unfamiliar distractors. In this case, the bottom-up and top-down activation may largely cancel out each other.

In summary, the current study demonstrated that the guidance with presence or absence of a shape feature (curvature and closure) was quite robust whereas familiarity-based guidance was much smaller in magnitude and only observed with an unfamiliar target but not with a familiar target. This suggests that the guidance by stimulus familiarity is qualitatively and quantitatively different from that by low-level features.

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