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Distractor ratio influences patterns of eye movements during visual search

Jiye Shen, Eyal M Reingold¶, Marc Pomplun
Department of Psychology, University of Toronto, 100 St George Street, Toronto, Ontario M5S 3G3, Canada; e-mail: reingold@psych.utoronto.ca
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Abstract. We examined the flexibility of guidance in a conjunctive search task by manipulating the ratios between different types of distractors. Participants were asked to decide whether a target was present or absent among distractors sharing either colour or shape. Results indicated a strong effect of distractor ratio on search performance. Shorter latency to move, faster manual response, and fewer fixations per trial were observed at extreme distractor ratios. The distribution of saccadic endpoints also varied flexibly as a function of distractor ratio. When there were very few same-colour distractors, the saccadic selectivity was biased towards the colour dimension. In contrast, when most of the distractors shared colour with the target, the saccadic selectivity was biased towards the shape dimension. Results are discussed within the framework of the guided search model.

How efficient are human observers in detecting a conjunctively defined search target, for example finding a red **X** among red **O**s and green **X**s? This issue has been systematically investigated over the past two decades (see Treisman 1988; Wolfe 1998 for a review). Search efficiency has been related to a number of factors, including stimulus similarity (Duncan and Humphreys 1989), target eccentricity (Carrasco et al 1995; Scialfa and Joffe 1998; Wolfe et al 1998), and stimulus dimensions (Quinlan and Humphreys 1987; Wolfe et al 1989).

Recently, several studies have demonstrated that the search efficiency also depends on the ratio between different types of distractors (Bacon and Egeth 1997; Egeth et al 1984; Kaptein et al 1995; Poisson and Wilkinson 1992; Zohary and Hochstein 1989). In one study by Zohary and Hochstein (1989), participants were asked to decide whether a red horizontal bar (RH) was present or absent among an array of red vertical (RV) and green horizontal (GH) bars. The search display was presented very briefly and then, after a variable interval (stimulus onset asynchrony, SOA), masked. One critical manipulation was the ratio between the two different types of distractors (RV versus GH) presented in any given array. The number of RV distractors ranged from 0 to 64 in increments of 4 while the total number of items was held constant at 64. Zohary and Hochstein found that the SOA required to reach a 70% correct response rate was a quadratic function of the number of distractors sharing colour with the search target. Detection was relatively easy for displays with extreme distractor ratios (ie either the RV or GH distractors were rare) but relatively difficult when each of the distractor types was equally represented. This pattern of results has been referred to as the distractor-ratio effect and has also been observed in studies measuring response times (Bacon and Egeth 1997; Poisson and Wilkinson 1992). The finding of change in search efficiency as a function of distractor ratio with a fixed display size is quite inconsistent with the original feature-integration theory (Treisman and Gelade 1980), which argued for a strictly item-by-item serial search in conjunction search tasks.

Traditionally, only response-time and error-rate data have been examined in visual search tasks but a growing number of studies have shown that eye-movement data provide convergent evidence. The examination of eye-movement variables such as the number

¶ Author to whom all correspondence and requests for reprints should be addressed.

of fixations per trial, latency to move and saccadic selectivity have yielded important information about the temporal and spatial characteristics of the search process (eg Findlay 1997; Gould 1967; Jacobs 1987; Luria and Strauss 1975; Motter and Belky 1998a, 1998b; Rayner and Fisher 1987; Scialfa and Joffe 1998; Viviani and Swensson 1982; D E Williams et al 1997; L G Williams 1967; Zelinsky and Sheinberg 1997; see Rayner 1998 for a review). The goal of the current study was to employ eye-movement measurement to further study the distractor-ratio effect.

1 Methods

1.1 *Subjects*

Twelve participants from an introductory psychology course were tested individually in two 1 h sessions. All participants had normal or corrected-to-normal visual acuity and normal colour vision. They were naïve with respect to the purpose of the experiment and received course credit for their participation.

1.2 *Apparatus*

The eyetracker employed in the current 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 19-inch Samsung SyncMaster 900P) and the other 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.

1.3 *Stimuli and design*

Stimuli were created by combining features on two dimensions: colour (red versus green) and shape (**X** versus **O**). This made a total of four different stimuli: a red **X**, a green **X**, a red **O**, and a green **O**. For each participant, one of these stimuli served as the search target and two others served as distractors such that one of them shared colour (same-colour distractor) and the other shared shape (same-shape distractor) with the target. For example, if a red **X** was designated as the search target, the distractors would consist of red **O**s and green **X**s (see figure 1 for an example). All stimuli were presented in a 15.5 deg × 15.5 deg field at a viewing distance of 91 cm. Each individual stimulus subtended 1.0 deg vertically and 0.8 deg horizontally and the minimum distance between the centres of neighbouring items was 1.8 deg. The red and green items were matched in luminance and presented on a white background.

The total number of stimuli presented in the display was fixed at 48. In target-absent trials, 3 to 45 (in multiples of 3) distractors shared colour with the target and the rest of the distractors shared shape with the target. Thus, there were 15 possible ratios of same-colour to same-shape distractors (3 : 45, 6 : 42, 9 : 39, 12 : 36, 15 : 33, 18 : 30, 21 : 27, 24 : 24, 27 : 21, 30 : 18, 33 : 15, 36 : 12, 39 : 9, 42 : 6, and 45 : 3). In target-present trials, a target-absent display was generated and then one of the distractors was randomly chosen to be replaced by the target stimulus.

Each participant performed 1200 trials in 20 blocks of 60, which amounted to 40 trials for each cell of the design (target presence × distractor ratio). The order of the stimulus displays was completely randomised with a restriction that no more than four displays of a given target presence or distractor ratio appeared in a row. Each participant completed the task in two individual sessions. At the beginning of each session, the participant received a practice block of 30 trials, with 1 trial for each possible combination of target presence and distractor ratio.

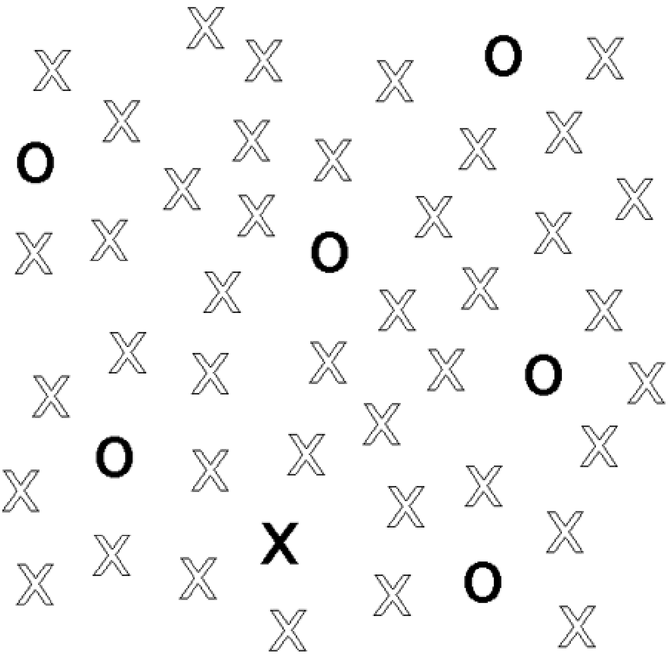

Figure 1. A sample display used in the current study. Red stimuli shown in black; green stimuli shown in white. Target was a red **X** and the distractors were green **X**s and red **O**s. This example corresponded to a target-present trial with a distractor ratio of 6 : 42.

1.4 *Procedure*

Participants were informed of the identities of the target and distractor stimuli before the experiment started. They were asked to look for the target item, and indicate whether it was in the display or not by pressing an appropriate button as quickly and accurately as possible. They were also told that the target could be either present or absent with equal probability.

A calibration procedure was performed at the beginning of the experiment. At the beginning of each trial, a fixation dot was presented in the centre of the screen in order to correct for drift in gaze position (see Stampe 1993). Participants were instructed to fixate on the dot and then press the start button to initiate a trial. The trial terminated if participants pressed one of the response buttons or if no response was made within 20 s. The time between display onset and the participant's response was recorded as the response time. The particular buttons used to indicate target presence or absence were counterbalanced across participants.

2 Results

For each participant, an outlier analysis was performed within each cell of the design (target presence × distractor ratio) to eliminate those response times (RTs) that were more than 3.0 standard deviations above or below the mean. This resulted in the removal of 1.9% of the trials from further analysis. Trials in which participants responded incorrectly (1.2% of all test trials) were also excluded from analysis; there was no evidence of a speed – accuracy tradeoff. Another 1.3% of the trials were dropped because of a saccade or blink overlapping the onset of a display.

2.1 *Response time and number of fixations per trial*

Figure 2a shows the mean and standard error of the RT plotted against the number of distractors which shared colour with the target (same-colour distractors). A 2 (target presence) × 15 (distractor ratio) repeated-measures ANOVA revealed significant main

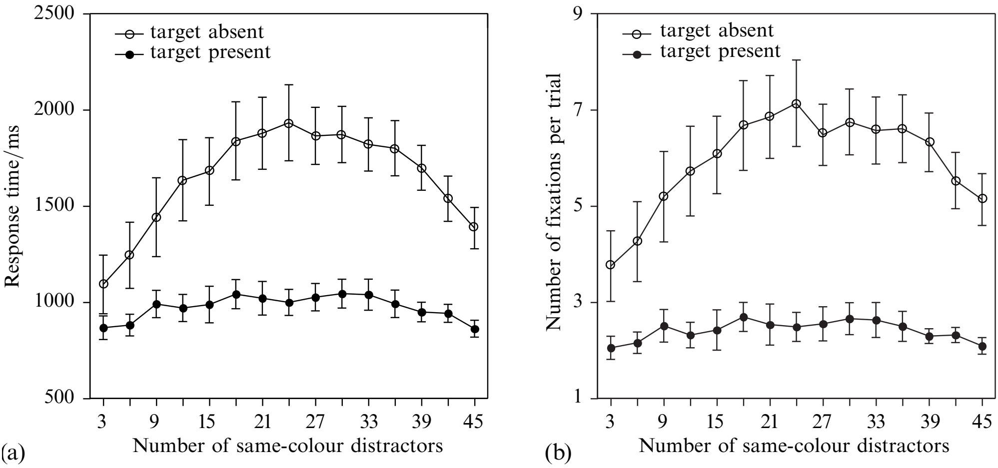

Figure 2. Mean correct response times (a), and average number of fixations per trial (b) as a function of the number of distractors sharing colour with the search target in target-absent trials and target-present trials.

effects of target presence ($F_{1,11} = 29.5$, $p < 0.001$) and distractor ratio ($F_{14,154} = 16.8$, $p < 0.001$). The interaction of target presence with distractor ratio was also significant ($F_{14,154} = 13.0$, $p < 0.001$). In target-absent trials, RT increased as a function of the number of items that shared colour with the target, up to the point at which the proportions of the two types of distractors (same-colour and same-shape) were roughly equivalent. At this point, RT decreased with the decreasing number of same-shape distractors (ie with the increasing number of same-colour distractors). However, the RT curve was not symmetrical. Response times were shorter in displays with few same-colour distractors than with few same-shape distractors. This may reflect the greater discriminability or salience of the colour dimension compared with the shape dimension in the present stimulus set (see also Motter and Belky 1998b; L G Williams 1967; Zohary and Hochstein 1989). In target-present trials, the magnitude of this effect was much smaller than that in target-absent trials and the RT curve was roughly symmetrical. Thus, consistent with the previous findings (Bacon and Egeth 1997; Poisson and Wilkinson 1992; Zohary and Hochstein 1989), search time was strongly influenced by the ratio between the two types of distractors when the display size was fixed. This indicates that participants did not perform a serial item-by-item search as postulated in the original feature-integration theory (Treisman and Gelade 1980).

The average number of fixations per trial was also calculated. As in previous studies (D E Williams et al 1997; Zelinsky and Sheinberg 1997), the number of fixations per trial revealed a qualitatively similar pattern to the RT data (figure 2b). There were main effects for target presence ($F_{1,11} = 56.1$, $p < 0.001$), and distractor ratio ($F_{14,154} = 17.8$, $p < 0.001$), as well as the interaction between target presence and distractor ratio ($F_{14,154} = 16.5$, $p < 0.001$). In target-absent trials, more fixations were made when both types of distractors were equally represented. When either same-colour distractors or same-shape distractors were rare, the number of fixations made decreased substantially. Consistent with the RT data, participants made an average of 1.5 more fixations in displays with few same-shape distractors than with few same-colour distractors. In target-present trials, the curve was again flat with slightly fewer fixations made when the distractor ratios substantially deviated from 1 : 1. The high similarity between the RT and number-of-fixations data is not surprising, given that both measures constitute global indicators of search efficiency (Scialfa and Joffe 1998; D E Williams et al 1997; Zelinsky and Sheinberg 1997).

2.2 *Latency to move*

Latency to move is defined as the interval between the onset of a display and the detection of the first eye movement. Therefore, it cannot be determined for single-fixation trials. For this reason, 6.9% of target-absent trials and 8.4% of target-present trials were dropped from further analysis. In figure 3 the latency to move is plotted as a function of the number of same-colour distractors.

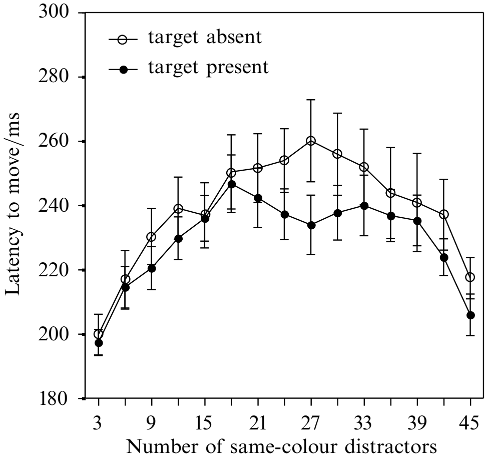

Figure 3. Average latency to move as a function of the number of same-colour distractors in target-absent and target-present trials.

Latency to move was slightly longer in target-absent trials than in target-present trials (239.1 versus 229.2 ms; $F_{1,11} = 6.7$, $p < 0.05$). For both target-present and target-absent trials, the latency to move was strongly influenced by the ratio between the two types of distractors ($F_{14,154} = 18.5$, $p < 0.001$). The initial latency was long when the ratio between same-colour and same-shape distractors was approximately 1 : 1 and was short when either type of distractor was relatively rare. This could be due to different lengths of delay in resolving the saccadic destination before the execution of the first saccade. There was also a significant interaction between target presence and distractor ratio ($F_{14,154} = 2.2$, $p < 0.01$). This interaction was due to an unexpected but systematic difference in the latency between target-absent and target-present trials which reached a maximum with 27 same-colour distractors.

2.3 *Saccadic selectivity*

For each fixation, the distance between the fixation position and every display item was computed and the fixation was assigned to the closest item. On target-present trials, fixations assigned to the target item were excluded from the analysis. The number of fixations assigned to each type of distractors (those sharing colour or shape with the target) was then summed to assess saccadic selectivity during search.

The frequencies of saccades directed to the distractors sharing colour with the search target in target-absent trials and target-present trials are plotted in figure 4a. The diagonal line in the figure depicts the expected probability of fixating same-colour distractors in the absence of selectivity (chance performance). An inspection of figure 4a reveals that the curves depicting the observed saccadic frequencies significantly deviate from the chance performance. The percentage of saccades directed to same-colour distractors was well above chance level with few same-colour distractors, but much lower than chance with few same-shape distractors. This pattern of results was quite robust and observed across all twelve participants. Thus, saccadic selectivity was clearly evident, changing flexibly as a function of distractor ratio.

To better assess the flexibility of saccadic selectivity, we plotted the saccadic bias towards the colour dimension as a function of the number of same-colour distractors

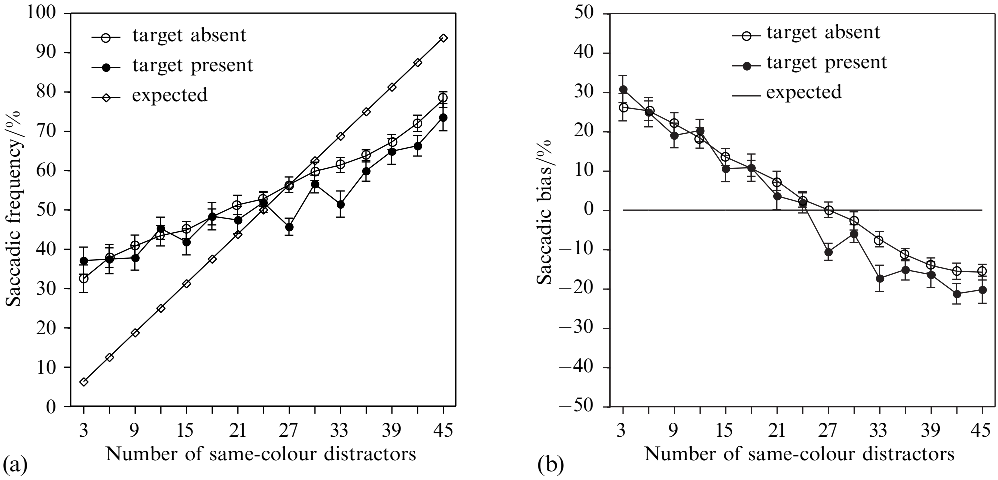

Figure 4. (a) Frequency of saccades directed to the same-colour distractors as a function of the number of same-colour distractors in target-absent and target-present trials. The diagonal line indicates the chance performance. (b) Saccadic bias (the difference between the observed frequency and chance performance) as a function of the number of same-colour distractors in target-absent and target-present trials.

across all saccades (figure 4b). The saccadic bias towards the colour dimension was calculated as the difference between the observed saccadic frequency to same-colour distractors and chance level. A positive bias value suggests that the saccadic selectivity favours the colour dimension whereas a negative value suggests that it favours the shape dimension. It is quite clear from figure 4b that the bias differed across distractor ratios in both target-absent and target-present trials ($F_{14,154} = 67.5$, $p < 0.001$). When there were only few distractors sharing colour with the target item, the saccadic selectivity was biased towards the colour dimension. The bias decreased almost linearly (especially in target-absent trials) with the increasing number of same-colour distractors. At the middle range of distractor ratios, the saccadic selectivity started to favour the shape dimension and the strength of this bias increased with the decreasing number of same-shape distractors (ie the increasing number of same-colour distractors). Furthermore, at extreme distractor ratios, the bias was stronger in the colour dimension than in the shape dimension. A planned comparison yielded a significant difference for three same-colour (28.5%) versus three same-shape distractors (18.0%; $F_{1,11} = 7.8$, $p < 0.01$). The difference for six same-colour (25.2%) versus six same-shape distractors (18.3%) approached significance ($F_{1,11} = 3.4$, $p = 0.092$).

Did saccade selectivity vary as a function of saccade sequence within a trial? To explore this, saccadic biases for the first saccades and subsequent saccades were calculated for the target-absent trials. This analysis was not conducted for the target-present trials because a large proportion of trials had fewer than two saccades. Figure 5 indicates that the bias in saccadic selectivity was apparent for both the first and subsequent saccades and varied as a function of the number of same-colour distractors ($F_{14,154} = 79.0$, $p < 0.001$). At extreme distractor ratios, the bias for the first saccades was much stronger than that for subsequent saccades, as indicated by a significant interaction between the saccade sequence (first saccades versus subsequent saccades) and distractor ratio ($F_{14,154} = 18.1$, $p < 0.001$). This difference was observed for displays with 3, 6, and 12 same-colour distractors and for displays with more than 30 same-colour distractors (ie fewer than 18 same-shape distractors).

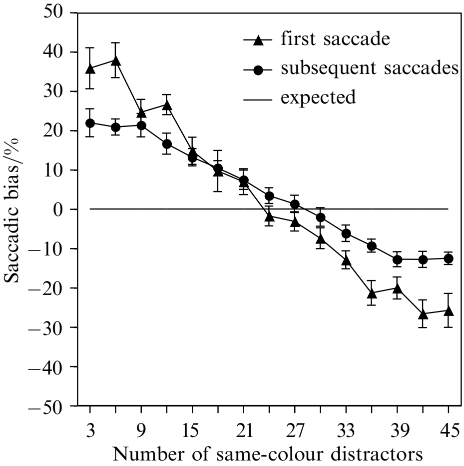

Figure 5. Saccadic bias as a function of the number of same-colour distractors for the first and subsequent saccades in target-absent trials.

3 General discussion

Consistent with previous studies, the ratio between different types of distractors in a conjunctive search task strongly influenced the response times (Bacon and Egeth 1997; Egeth et al 1984; Kaptein et al 1995; Poisson and Wilkinson 1992; Zohary and Hochstein 1989). When the total number of items presented in a display was kept constant, the response times varied quadratically as a function of the ratio between two types of distractors. Manual response was faster when either type of distractor was rare than when both types of distractors were equally represented. This indicates that detecting a conjunctively defined target does not necessarily require a serial item-by-item search as proposed in the original feature-integration theory (Treisman and Gelade 1980). We also found that the observed changes in RT due to the distractor ratio were echoed by eye-movement measures, such as the number of fixations per trial and latency to move. More importantly, the present investigation revealed the flexibility of saccadic selectivity as a function of distractor ratio. When there were only few same-colour distractors, the saccadic selectivity was biased towards the colour dimension. In contrast, when most of the distractors shared colour with the search target, the saccadic selectivity was biased towards the shape dimension. At extreme distractor ratios, saccadic selectivity also varied as a function of the saccadic sequence within a trial. Bias was stronger for the first saccades than for the subsequent saccades.

Results from the current study are consistent with the guided search model (Wolfe 1994; Wolfe et al 1989), which argues that information extracted preattentively can guide shifts of attention during the search process. According to that model, the preattentive information encompasses both bottom–up and top–down activations. These sources of information are combined to form an 'activation map', which contains peaks of activity at likely target locations (Wolfe 1994). The focus of attention is directed serially to the locations with highest activation until the target is found or the criterion to make a negative response is reached. When participants are allowed to move their eyes, a 'saccade map' is similarly created to guide the movements of the eyes (Wolfe and Gancarz 1996; see the 'salience map' by Findlay and Gilchrist 1998 or 'saliency map' by Henderson and Hollingworth 1998 for similar ideas). Every 200–250 ms, the eyes are moved to the point of highest activation in the saccade map (Wolfe and Gancarz 1996).

In the absence of explicit instructions for particular search strategies, the bottom–up activation may be largely responsible for the efficient search at the extreme distractor ratios and the patterns of eye movements observed in the current study. Let us imagine a display with very few same-shape distractors. The bottom–up activation, computed as the difference between the element in question and every other element in the display (Cave and Wolfe 1990), or between that element and the neighbouring elements (Wolfe 1994; see also Poisson and Wilkinson 1992), would be relatively large at locations occupied by the same-shape distractors. Upon seeing such a display, participants would likely direct their first saccades to the location with peak activity in the hypothetical saccade or salience map (Findlay and Gilchrist 1998; Henderson and Hollingworth 1998; Wolfe and Gancarz 1996). As a result, the endpoints for the first saccade would tend to be biased towards distractors sharing the same shape with the target. Furthermore, the latency to move would be relatively short because the bottom – up activation is strong and the saccadic endpoint could be selected faster. Attention and eye movements are then guided from the point of highest activation to the next highest. It is possible that this process mediates the sequential effect of saccadic selectivity within a single trial. That is, the saccadic bias is stronger for the first saccades than for the subsequent saccades. In displays with very few same-colour distractors, similar patterns of eye movements can also be observed. In contrast, when the proportions of both types of distractors are roughly equal, the bottom – up activation alone may not provide a strong cue for guidance because each element shares colour with half of the items and shares shape with the other half of the items (Wolfe 1994).

In addition to bottom – up activation, the distractor ratio effect may also be mediated by top – down activation. This can be achieved by postulating an initial global assessment of the visual display based on the proportion of each type of distractor. Then the top – down activation is directed to the distractors belonging to the smaller group (Zohary and Hochstein 1989). Bacon and Egeth (1997) provided evidence for top – down control in a recent study. They manipulated the distractor ratios and instructed the participants to selectively attend to distractors of either the colour subset or the orientation subset. With exactly the same search display (ie with same bottom – up activation), they found that RTs for instruction-consistent trials were shorter than for instruction-inconsistent trials. The current study, especially the sequential saccadic selectivity analysis, however, does not provide direct evidence for top – down control in mediating the distractor-ratio effect.

There have been a number of studies demonstrating saccadic selectivity in conjunction search tasks. Stimulus dimensions such as colour, orientation, shape, size, and contrast have been shown to bias the distribution of saccadic endpoints (Findlay 1997; Findlay and Gilchrist 1998; Hooge and Erkelens 1999; Luria and Strauss 1975; Motter and Belky 1998b; Scialfa and Joffe 1998; Shen and Reingold 1999; D E Williams and Reingold, forthcoming; L G Williams 1967; but see Zelinsky 1996). The current study adds to this growing literature. The unique contribution of the present investigation, however, is the demonstration of the flexibility of saccadic selectivity. In most of previous studies, one stimulus dimension (eg colour) 'dominated' the search process over other stimulus dimensions (eg shape or orientation), and the saccadic selectivity was consistently biased towards those distractors belonging to the dominant dimension. The current study demonstrated that the bias in saccadic selectivity is not absolute and can be reversed by changing the distractor ratio. The current study also revealed the temporal dynamics of guidance within a single trial. At extreme distractor ratios, a stronger saccadic selectivity was found for the first saccades than for the subsequent saccades.

In summary, the current study demonstrated that in addition to response time and accuracy, a number of eye-movement variables such as the number of fixations per trial, latency to move, and saccadic selectivity, varied as a function of distractor ratio. Results from the current investigation provide further evidence that patterns of eye movements constitute a powerful tool for investigating the attentional processes underlying visual search.

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References

Bacon W F, Egeth H E, 1997 "Goal-directed guidance of attention: Evidence from conjunctive visual search" *Journal of Experimental Psychology: Human Perception and Performance* **23** 948 – 961

Carrasco M, Evert D L, Chang I, Katz S M, 1995 "The eccentricity effect: Target eccentricity affects performance on conjunction searches" *Perception & Psychophysics* **57** 1241 – 1261

Cave K R, Wolfe J M, 1990 "Modeling the role of parallel processing in visual search" *Cognitive Psychology* **22** 225 – 271

Duncan J, Humphreys G W, 1989 "Visual search and stimulus similarity" *Psychological Review* **96** 433 – 458

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

Findlay J M, 1997 "Saccade target selection during visual search" *Vision Research* **37** 617 – 631

Findlay J M, Gilchrist I D, 1998 "Eye guidance and visual search", in *Eye Guidance in Reading and Scene Perception* Ed. G Underwood (Oxford: Elsevier) pp 295 – 312

Gould J D, 1967 "Pattern recognition and eye movement parameters" *Perception & Psychophysics* **2** 399 – 407

Henderson J M, Hollingworth A, 1998 "Eye movements during scene viewing: An overview", in *Eye Guidance in Reading and Scene Perception* Ed. G Underwood (Oxford: Elsevier) pp 269 – 293

Hooge I Th C, Erkelens C J, 1999 "Peripheral vision and oculomotor control during visual search" *Vision Research* **39** 1567 – 1575

Jacobs A M, 1987 "Toward a model of eye movement control in visual search", *in Eye Movements: From Physiology to Cognition* Eds J K O'Regan, A Lévy-Schoen (Amsterdam: North Holland) pp 275 – 284

Kaptein N A, Theeuwes J, Heijden A H C van der, 1995 "Search for a conjunctively defined target can be selectively limited to a color-defined subset of elements" *Journal of Experimental Psychology: Human Perception and Performance* **21** 1053 – 1069

Luria S M, Strauss M S, 1975 "Eye movements during search for coded and uncoded targets" *Perception & Psychophysics* **17** 303 – 308

Motter B C, Belky E J, 1998a "The zone of focal attention during active visual search" *Vision Research* **38** 1007 – 1022

Motter B C, Belky E J, 1998b "The guidance of eye movements during active visual search" *Vision Research* **38** 1805 – 1815

Poisson M E, Wilkinson F, 1992 "Distractor ratio and grouping processes in visual conjunction search" *Perception* **21** 21 – 38

Quinlan P T, Humphreys G W, 1987 "Visual search for targets defined by combinations of color, shape, and size: An examination of the task constraints on feature and conjunction searches" *Perception & Psychophysics* **41** 455 – 472

Rayner K, 1998 "Eye movements in reading and information processing: 20 years of research" *Psychological Bulletin* **124** 372 – 422

Rayner K, Fisher D L, 1987 "Eye movements and the perceptual span during visual search", in *Eye movements: From Physiology to Cognition* Eds J K O'Regan, A Lévy-Schoen (Amsterdam: North-Holland) pp 293 – 302

Scialfa C T, Joffe K M, 1998 "Response times and eye movements in feature and conjunction search as a function of target eccentricity" *Perception & Psychophysics* **60** 1067 – 1082

Shen J, Reingold E M, 1999 "Saccadic selectivity during visual search: The effects of shape and stimulus familiarity", in *Proceedings of the Twenty-First Annual Conference of the Cognitive Science Society* Eds M Hahn, S C Stoness (Mahwah, NJ: Lawrence Erlbaum Associates) pp 649 – 652

Stampe D, 1993 "Heuristic filtering and reliable calibration methods for video-based pupil tracking systems" *Behavior Research Methods, Instruments, and Computers* **25** 137 – 142

Treisman A, 1988 "Features and objects: The fourteenth Bartlett memorial lecture" *Quarterly Journal of Experimental Psychology A* **40** 201 – 237

Treisman A, Gelade G, 1980 "A feature-integration theory of attention" *Cognitive Psychology* **12** 97 – 136

Viviani P, Swensson R G, 1982 "Saccadic eye movements to peripherally discriminated visual targets" *Journal of Experimental Psychology: Human Perception and Performance* **8** 113 – 126
Williams D E, Reingold E M, forthcoming, "Preattentive guidance of eye movements during triple conjunction search tasks: The effects of feature discriminability and saccadic amplitude" *Psychonomic Bulletin and Review*
Williams D E, Reingold E M, Moscovitch M, Behrmann M, 1997 "Patterns of eye movements during parallel and serial visual search tasks" *Canadian Journal of Experimental Psychology* **51** 151 – 164
Williams L G, 1967 "The effects of target specification on objects fixated during visual search" *Acta Psychologica* **27** 355 – 360
Wolfe J M, 1994 "Guided search 2.0: A revised model of visual search" *Psychonomic Bulletin and Review* **1** 202 – 238
Wolfe J M, 1998 "Visual search", in *Attention* Ed. H Pashler (London: Psychology Press) pp 13 – 71
Wolfe J M, Cave K R, Franzel S L, 1989 "Guided search: An alternative to the feature integration model for visual search" *Journal of Experimental Psychology: Human Perception and Performance* **15** 419 – 433
Wolfe J M, Gancarz G, 1996 "Guided Search 3.0", in *Basic and Clinical Applications of Vision Science* Ed. V Lakshminarayanan (Dordrecht: Kluwer) pp 189 – 192
Wolfe J M, O'Neill P, Bennett S C, 1998 "Why are there eccentricity effects in visual search? Visual and attentional hypotheses" *Perception & Psychophysics* **60** 140 – 156
Zelinsky G J, 1996 "Using eye saccades to assess the selectivity of search movements" *Vision Research* **36** 2177 – 2187
Zelinsky G J, Sheinberg D L, 1997 "Eye movements during parallel – serial visual search" *Journal of Experimental Psychology: Human Perception and Performance* **23** 244 – 262
Zohary E, Hochstein S, 1989 "How serial is serial processing in vision?" *Perception* **18** 191 – 200