

Stable individual differences in search strategy?: The effect of task demands and motivational factors on scanning strategy in visual search

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Previous studies have demonstrated large individual differences in scanning strategy during a dynamic visual search task (E. Becic, A. F. Kramer, & W. R. Boot, 2007; W. R. Boot, A. F. Kramer, E. Becic, D. A. Wiegmann, & T. Kubose, 2006). These differences accounted for substantial variance in performance. Participants who chose to search covertly (without eye movements) excelled, participants who searched overtly (with eye movements) performed poorly. The aim of the current study was to investigate the stability of scanning strategies across different visual search tasks in an attempt to explain why a large percentage of observers might engage in maladaptive strategies. Scanning strategy was assessed for a group of observers across a variety of search tasks without feedback (efficient search, inefficient search, change detection, dynamic search). While scanning strategy was partly determined by task demands, stable individual differences emerged. Participants who searched either overtly or covertly tended to adopt the same strategy regardless of the demands of the search task, even in tasks in which such a strategy was maladaptive. However, when participants were given explicit feedback about their performance during search and performance incentives, strategies across tasks diverged. Thus it appears that observers by default will favor a particular search strategy but can modify this strategy when it is clearly maladaptive to the task.

Keywords: task demand, visual search, scanning strategy

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Introduction

Visual search describes the sometimes difficult process of finding a target item among distractor items in often cluttered visual environments. The difficulty of visual search arises from physical and cognitive processing limitations that can prevent us from instantly recognizing the presence of a target item in a single glance. Attention is required to focus limited processing resources on specific regions of a scene in order for us to find the people and objects for which we are searching. For example, when searching for a friend arriving at a busy airport, you might direct your attention to the faces of a number of individuals before finding your friend. Researchers have proposed a number of factors, both stimulus-related and cognitive, that influence where and how attention is allocated during visual search.

The manner in which attention is allocated during search appears to be partially determined by the visual properties of the scene being searched. For example,

attention can be captured by certain visual features such as onsets (e.g., Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999; Yantis & Jonides, 1984) and unique colors (e.g., Theeuwes, 1994; Theeuwes & Burger, 1998). Evidence suggests that even when observers know exactly where the target of their search will appear, highly salient features known never to be associated with the target item can still capture attention in a seemingly stimulus-driven manner (Christ & Abrams, 2006). These findings suggest that in certain situations, visual salience plays a dominant role in controlling the direction of attention. Consistent with this notion, some models of visual attention predict the allocation of attention based largely or solely on the visual properties of a scene (e.g., Itti, 2006; Itti & Koch, 2000). However, cognitive or top-down factors also appear to play an important role. Attention is often allocated to objects sharing common features with a target object, suggesting that the goal or “attention set” of the observer plays a significant role in determining the allocation of attention (e.g., Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). In other words,

observers can modify their top-down attentional control settings depending on the nature of the task to allow efficient guidance of attention to the target. Attentional guidance in the form of memory for which items have already been searched, and memory for previous encounters with repeated search displays, also point to an important role of top-down control (Boot, McCarley, Kramer, & Peterson, 2004; Brockmole & Henderson, 2006; Peterson & Kramer, 2001). Consistent with these findings, other models and theories of visual attention predict the allocation of attention based on both top-down and bottom-up factors, with top-down factors playing a significant or dominant role (e.g., Heinke, Humphreys, & Tweed, 2006; Henderson, Brockmole, Castelhana, & Mack, 2007; Wolfe, 1994).

An often-overlooked factor that has recently received more attention is the role individual differences play in determining how attention is allocated during search. These individual differences may be an important endogenous factor to consider when predicting the allocation of attention and, subsequently, performance. It is clear that expertise can have a profound impact on how attention is allocated. Expertise influences the allocation of visual attention in tasks such as piloting, surgery, and sports such as hockey and soccer (e.g., Bellenkes, Wickens, & Kramer, 1997; Law, Atkins, Kirkpatrick, Lomax, & Mackenzie, 2004; Rendell & Morgan, 2005; Savelsbergh, Williams, van der Kamp, & Ward, 2002). However, less is known about individual differences in scanning strategies of non-experts. Andrews and Coppola (1999) compared eye movement parameters (saccade length and fixation duration) of non-experts while they engaged in a number of free-viewing conditions, a visual search task (searching for Waldo), and reading. For each individual, oculomotor behavior in the free-viewing conditions (viewing simple patterns, complex scenes, and viewing in the dark) was similar, as was oculomotor behavior during reading and visual search. However, although oculomotor behavior was similar across the two active viewing tasks (reading and visual search), these similarities do not necessarily suggest strategic individual differences and may instead reflect individual differences in visual processing ability. More recently, Castelhana and Henderson (2008) explored this topic by comparing participants' eye movements across a number of scene and face viewing tasks. Participants were asked to study pictures of different types (line drawings, 3-D rendered scenes, and photographs) in anticipation of a memory test. Castelhana and Henderson found extremely high correlations (r 's > 0.9) between eye movement parameters such as fixation duration and saccade length as participants viewed these different image types, suggesting stable individual differences. This basic result was also obtained when participants viewed faces and houses, as well as when images were altered with artificial scotomas of various sizes. Finally, Rayner, Xingshan, Williams, Cave, and Well (2007) had participants who were native English speakers,

native Chinese speakers, or who were bilingual perform a number of reading and search tasks and found stable eye movement differences across individuals. Even more interesting, cultural differences were observed as well, with Chinese participants spending more time looking at background information and less at foreground information compared to American participants. All of these studies together suggest that an understanding of endogenous factors such as individual differences in eye movement behavior are required to predict how attention might be allocated in a variety of contexts.

The current research seeks to further evaluate and understand individual differences in visual search behavior in the context of search tasks in which poor strategies can have a major impact on performance (unlike previous studies in which task performance was either not evaluated or individual differences were not examined in the context of task performance). Previous results indicate that a simple metric of search strategy (the rate of eye movements during search) can explain up to 73% of the variance in the detection of a dynamic target (Boot, Kramer, Becic, Wiegmann, & Kubose, 2006). In this search paradigm (which we will refer to as the dynamic dot detection task), participants viewed dynamic displays in which up to 24 objects (dots) moved across the display. During some trials a new dot appeared in the display and the task of the participant was to push a button when this occurred. For such a simple task, a surprisingly large range in accuracy was observed, with some participants almost always detecting the new dot and others missing 50% or more of the onset events. These large differences in accuracy led us to investigate the role of scanning strategies. As a simple measure of scanning strategy, we examined the number of eye movements made during control trials in which no change occurred and classified observers as either covert searchers (i.e., participants who searched without making many eye movements) or overt searchers (i.e., participants who moved their eyes around the display to detect the target). We found a strong linear relationship between the number of eye movements and accuracy of detection. Participants who chose to move their eyes frequently did poorly. Participants who did not move their eyes performed the best. In other words, the more participants moved their eyes among moving objects in the display, the fewer targets they detected. Interestingly, this relationship between strategy and performance was still observed when trials on which the target appeared shortly before, during, or shortly after the initiation of a saccade were excluded from analysis to reduce the effect of saccadic suppression (Ross, Morrone, Goldberg, & Burr, 2001). The relationship between saccade rate and performance was weaker but still present. Thus, although saccadic suppression appears to play a role in explaining the relationship between strategy and performance, other factors may be important as well.

Why is it that some participants chose to engage in such a maladaptive scan strategy (see also Araujo, Kowler, &

Pavel, 2001; Zelinsky & Sheinberg, 1997)? One possible explanation might be that the overt search strategy observed in our previous study is actually adaptive for those who engage in it. For example, previous research has shown that individuals differ in the breadth of their useful field of view or attentional field (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ball, Beard, Roenker, Miller, & Griggs, 1988). Individuals with a small attentional field might perform poorly when required to covertly search a large dynamically changing display. However, the second experiment of Boot et al. (2006) ruled out this explanation. Participants who naturally searched overtly were instructed to search covertly. After receiving this instruction, their performance matched the performance of those who naturally adopted a covert strategy. Conversely, covert searchers instructed to search overtly performed just as poorly as participants who naturally adopted that strategy. Thus, participants were able to rapidly modify their search strategy when instructed, and in the case of naturally overt searchers, substantially improve their performance. This would seem to be unlikely if search strategy was strongly dependent on the size of an individual's attentional field or individual differences in visual processing.

The current study seeks to explore whether stable individual differences in scanning strategies might explain the maladaptive scan strategy that we observed for participants in our dynamic search task. Although this study cannot answer the question of what mechanism(s) might underlie these stable individual differences, it can highlight the fact that performance in a number of tasks can be strongly affected by the default strategy a participant might bring to a task. Furthermore, the current study explores the degree to which this strategy might be modulated by task demands, feedback, and motivation. This work builds on previous research demonstrating stable individual differences in scanning behavior but goes further by examining specific cases in which an individual's oculomotor behavior can have profound effects on task performance. If these individual differences really are stable, then they should be observed even in cases in which the demands of the task make this strategy harmful to performance. Additionally, the current study used a wider variety of search tasks compared to previous studies, including a dynamic search task and a driving-related search task. Finally, we examine the strength of the preference to use one strategy over another by providing incentive to use another strategy.

In the present study, the same group of participants was administered a number of tasks in which either a covert or overt search strategy could be adopted. In [Experiment 1](#), participants were asked to perform the previously described dynamic dot detection task (Boot et al., 2006), an efficient search task (a tilted line among vertical lines), an inefficient search task (a T among Ls), and a change blindness task in which participants searched for changes in driving scenes. These tasks vary in the degree to which an overt or covert strategy might be effective. The tasks

were specifically chosen such that two would require focal attention to the target (change blindness and inefficient search) and two would not (dynamic dot detection task and efficient search task). In difficult and inefficient search tasks, a covert search strategy would be highly maladaptive due to the difficulty of discriminating complex stimuli in the periphery. Foveal discrimination is typically required to detect a target very similar to distractor items, or a change not accompanied by a transient signal as is typical of change blindness paradigms (see Simons & Ambinder, 2005 for a review of the change blindness literature). However, in an efficient or easy search task, eye movements might hinder performance by focusing attention on individual items rather than allowing the unique target item to pop-out (Smilek, Enns, Eastwood, & Merikle, 2006). If participants adopt a maladaptive scan strategy in the dynamic dot detection task because it is their naturally adopted strategy for most visual search tasks, then the rate of eye movements in that task should be correlated with the rate of eye movements made during other search tasks. This would suggest that participants have idiosyncratic search strategies that they apply to a number of search tasks, regardless of the actual search task demands. The inclusion of the dynamic dot detection task is critical since it excludes the possibility that similarities in strategy do not necessarily suggest strategic individual differences but instead reflect individual differences in visual processing ability. Performance in this task has been shown to be almost exclusively driven by strategy (Boot et al., 2006).

To preview the results of [Experiment 1](#), participants generally adopted the same strategy across tasks. For example, covert searchers tended to be covert searchers in both the dynamic dot detection task and the inefficient search task, even though this strategy was helpful in one task and harmful in the other. To further explore the stability of scan strategies, [Experiment 2](#) gave participants explicit trial-by-trial feedback about performance and an incentive (monetary reward) to perform as well as possible. If search strategy is similar across tasks even with feedback and an incentive to do well, scanning strategy would represent a relatively stable and immutable individual difference. However, if strategy is modifiable with feedback and reward, scanning strategy would represent a weaker and malleable preference.

Experiment 1

Methods

Participants

Forty undergraduate students from the University of Illinois at Urbana-Champaign participated in [Experiment 1](#). All participants exhibited normal or corrected-to-normal

vision and passed the Ishihara color blindness test. The experiment was completed in two sessions and participants were paid \$8/hour for their participation. Each session took approximately 40 to 60 minutes.

Apparatus

All stimuli were generated by a Dell computer with 256 MB of RAM and a Pentium 4 processor (2.66 GHz) and were presented on a 19" color monitor. An EyeLink II eye tracker was used to record eye movements with a temporal resolution of 500 Hz and a spatial resolution of 0.2° . An eye movement was classified as a saccade if its distance exceeded 0.2° and either its acceleration reached 9500 deg/sec^2 or its velocity reached 30 deg/sec . A chin rest was used to minimize head movements while participants were seated 55 cm from the display.

Stimuli and tasks

Participants performed four different search tasks, two of which could be performed well without eye movements (a pop-out search task and the dynamic dot task), and two of which required a more overt strategy given the difficulty of target detection (a serial search task and a change blindness task). An equal number of covert and overt tasks were selected to discourage a bias for one strategy over another, and the order of tasks was counter-balanced to minimize the influence of order effects.

Dynamic dot detection

The dynamic dot detection display consisted of different colored dots (red, blue, and green) moving across a gray circular background (see Figure 1). Dots moved with a constant velocity of 0.82 deg/second on a linear path. Each dot measured 0.48 degrees in diameter and was randomly assigned a travel path of $0, 45, 90, 135, 180, 225, 270,$ or 315 degrees from its starting location. In advance, a path was calculated for each dot that would not take the dot off of the gray circular display during an 8-second trial. The initial distribution of dots was constrained such that an equal number of dots appeared in all four quadrants of the circular display. The gray background on which dots traveled measured 25 degrees in diameter and had a luminance of 11.8 cd/m^2 (RGB: 90, 90, 90). The luminance of the red, blue, and green dots was 9.8 (RGB: 168, 0, 0), 5.0 (RGB: 0, 0, 166), and 12.7 cd/m^2 (RGB: 0, 114, 0), respectively. An onset (a new dot) appeared on 67% of the trials. This dot could appear anywhere in the display but was also constrained such that it would not leave the screen. The color of the new dot was equally likely to be red, blue, or green and occurred 1, 3, or 5 seconds following the start of a trial. On the remainder of the trials (33%) no new dot appeared.

A trial began after the participant pushed a button and fixated the cross at the center of the screen. Each trial included 23 dynamically moving dots and continued until either the participant responded or 8 seconds elapsed. The goal of the task was to detect the onset of a new item in the display and press a button as quickly

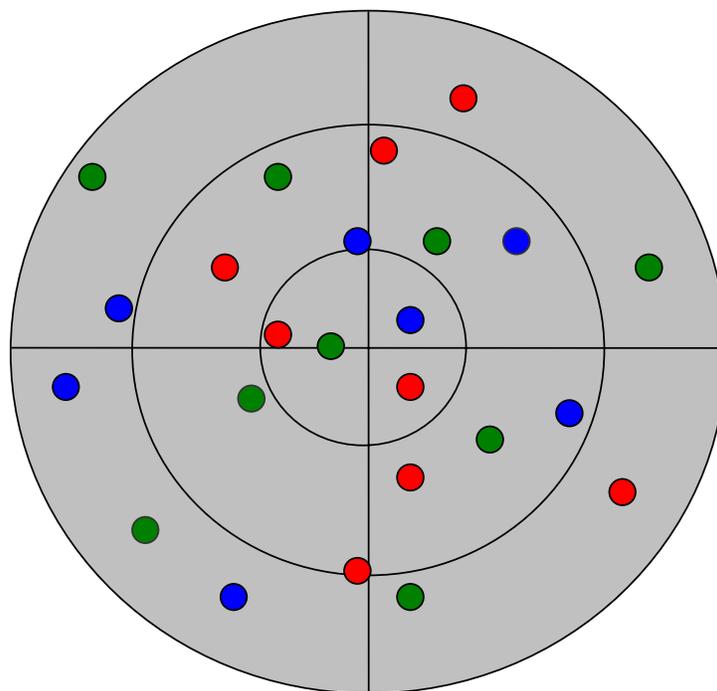


Figure 1. An example of the displays viewed by the participants with red, blue, and green dots moving across the gray background.

as possible following onset detection. A total of one block of 144 trials was completed by each observer.

Change blindness task

In the change blindness task, the displays consisted of images of driving scenes from the perspective of an automobile driver (McCarley et al., 2004; Pringle, Irwin, Kramer, & Atchley, 2001). It has been demonstrated that fixation location (and thus overt attention) is an important factor in detecting changes to a scene when the transient signal of the change is masked (Henderson & Hollingworth, 1999). Based on this finding it was predicted that an overt strategy would be more beneficial. Each trial began with an image presented on the screen for 240 ms, followed by a gray screen presented for 80 ms, and then the same image with something in the scene changed for 240 ms. This sequence was repeated for 20 seconds, or until participants made a response. Participants were asked to find the change. Changes included color changes (e.g., cars changing color), location changes (e.g., pedestrians stepping into the road), and additions/deletions (e.g., signs appearing and disappearing). Upon finding the change participants pressed a key on the keyboard and verbally described the change. Their verbal responses were recorded for later transcription. Participants completed 38 trials.

Efficient visual search

The displays for the efficient visual search task consisted of a tilted line among varying numbers of vertical lines. All the lines measured 0.86 degrees in length. The target line was tilted 45° either to the left or the right. The gray background on which the lines were presented had a luminance of 63.3 cd/m² (RGB: 200, 200, 200) and the black lines had a luminance of 0.2 cd/m² (RGB: 0, 0, 0). Stimulus location was based on an imaginary 6 × 8 grid. Stimuli were randomly assigned to appear within the cells of this grid but could be randomly jittered plus or minus 1 degree from the center of the cell in the *X* or *Y* direction. The minimum center-to-center distance between stimuli was approximately 3 degrees. The participant's task was to determine whether the target was tilted to the left or to the right and press one of two response buttons as quickly as possible. Participants viewed displays with set sizes of 4, 8, and 12 items. Participants completed 168 trials equally divided between each set size.

Inefficient visual search

The displays for the inefficient visual search task consisted of a letter T among varying number of L shapes. The width and the height of both L shapes and T letters were 0.86 degrees. The target (letter T) was rotated 90° or

270° angle while L shape distractors were rotated 0, 90, 180, and 270 degrees. To make the search more difficult, the two lines of each L shape distractor were offset by 0.2 degrees, making the L shapes more similar to the T target. The spatial distribution of stimuli was the same as the efficient search task. The participant's task was to determine whether the stem of the target item pointed to the left or to the right by pressing one of two buttons. The luminance and the color of the background and the target/distractors were the same as in the efficient search task. There were three different set sizes of 4, 8, and 12 items. Participants completed 168 trials equally divided between each set size.

Procedure

Participants completed these four tasks over two sessions. The order of the tasks was counterbalanced with the caveat that the two static search tasks (efficient and inefficient) were performed one after the other on the same day, with the order of the first static search task being counterbalanced. The second session was performed within four days of the first session. On the first session, participants completed three tasks. On the second day, participants completed one task along with an unrelated task that occurred at the end of the session. Participants were informed of equal importance of speed and accuracy in all four tasks and were instructed to respond as quickly and as accurately as possible. Feedback was withheld to assure that participants did not adjust their scanning strategy based on performance in an attempt to observe the strategy participants would bring to each task by default.

Results

We begin by presenting the average accuracy and response time data for the four search tasks. Then we examine the effects of scanning strategy on performance. Finally, we present data on the stability of scanning strategies across different search tasks.

Trial inclusion

Due to a computer error, data from one participant was lost in the dynamic dot detection task. This participant's data in the other three tasks were included when performing analyses for those tasks but not when comparing these tasks to the dynamic dot detection task. In the dynamic dot detection task, the first 20 trials were considered practice and were not included in the analyses. In addition, trials in which the target stimulus was occluded by another item at the time of onset were excluded from the analysis (7.1% of trials) and trials in which the critical

change occurred during a saccade (3.8% of trials) were also excluded to reduce the effects of saccadic suppression (Ross et al., 2001). A response that occurred within 1.5 seconds after the appearance of the new target was scored as correct. Responses that occurred before the appearance or later than 1.5 seconds after the appearance of the target were considered false alarms and occurred on 2.4% of trials.

For the change blindness task, participants very rarely indicated a change without being able to verbalize correctly the nature of the change (<1% of trials). Thus all trials on which participants responded were included in the analyses. The change blindness task included a separate block of practice trials that was not analyzed. In the efficient and inefficient static visual search tasks, the first 10 trials were considered practice and were not included in the analyses. In all tasks, only accurate response times were analyzed.

Accuracy and response time

Figure 2 represents the accuracy rate for each of the four search tasks, and Figure 3 represents response times. Accuracy for both the dynamic dot detection task and the change blindness task were fairly comparable (82% and

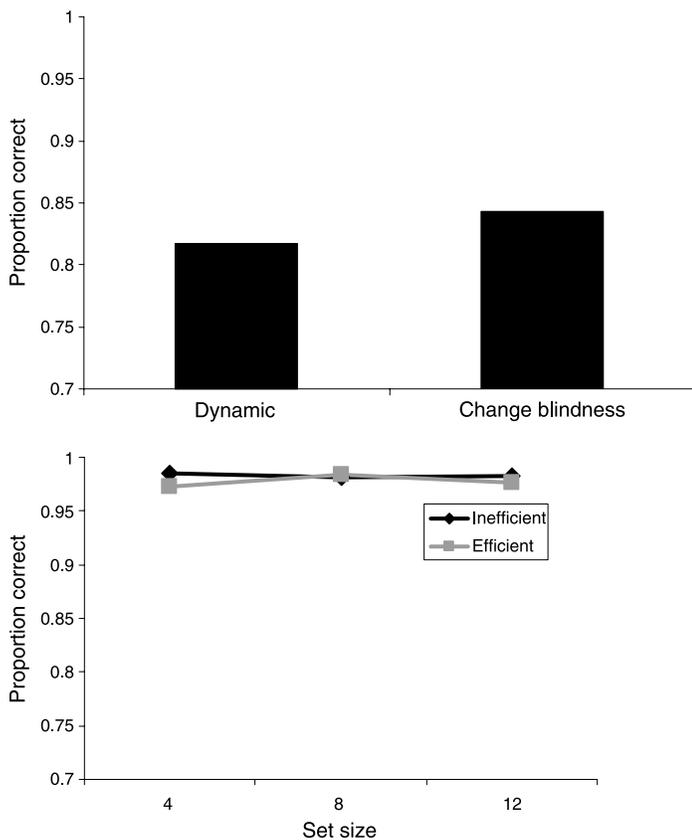


Figure 2. The average accuracy for (top panel) dynamic dot detection and change blindness tasks and (bottom panel) efficient and inefficient static visual search tasks.

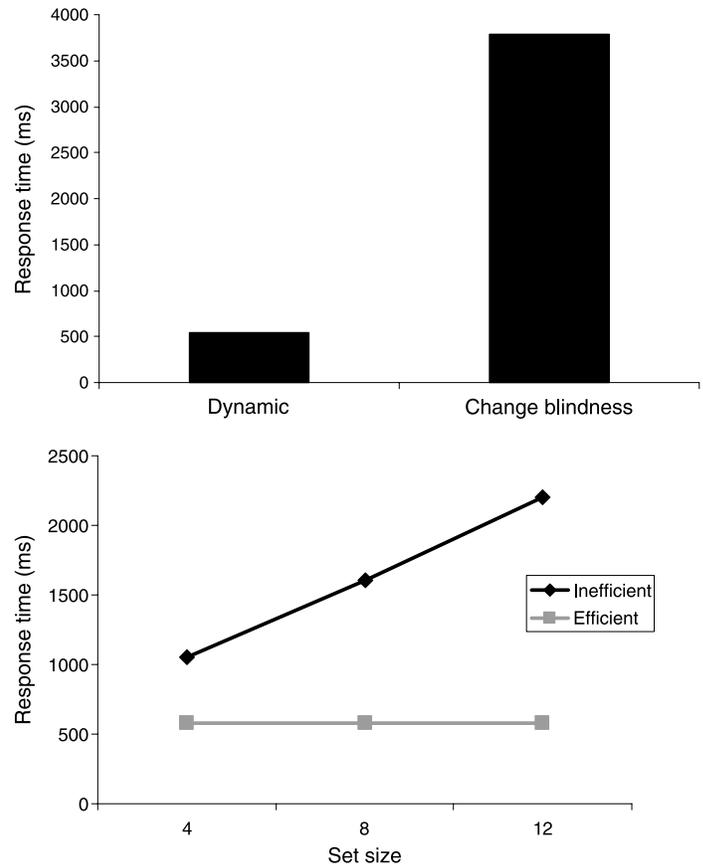


Figure 3. The average response times for (top panel) dynamic dot detection and change blindness tasks and (bottom panel) efficient and inefficient static visual search tasks.

84%, respectively). However, not surprisingly, response times were much longer in the change blindness task.

To make sure search efficiency was indeed different in the two static search tasks (efficient and inefficient), accuracy and speed were compared directly. From Figure 2, it is clear that accuracy for both efficient and inefficient static search tasks was near ceiling for all set sizes. A repeated-measures ANOVA with task (efficient or inefficient) and set size (4, 8, or 12 items) as factors was performed on accuracy data. This ANOVA revealed no effect of task ($F(1, 39) = 3.80, p = 0.06$), no effect of set size ($F(2, 78) = 1.32, p = 0.27$), and no reliable interaction between task and set size ($F(2, 78) = 2.84, p = 0.06$). Although not statistically significant, there was a trend for errors to be slightly higher for the efficient search task at the smallest set size. An identical ANOVA was performed on response time data. This revealed a significant main effects of task ($F(1,39) = 463.95, p < 0.001$) and set size ($F(2,78) = 206.01, p < 0.001$). A set size by task interaction was also present ($F(2,78) = 221.74, p < 0.001$). The source of this interaction was driven by differences in search efficiency. The average search slope in the inefficient visual search task was 143 ms per item while the average search slope for the efficient search task

was 1 ms per item. Slopes were significantly different from zero in the inefficient search task ($t(39) = 16.19$, $p < 0.001$) but not for the efficient search task ($t(39) = 0.67$, $p = 0.50$).

Having established performance in terms of speed and accuracy for each task, we now turn to examining the relationship between scanning behavior and performance. It is predicted, based on previous results, that participants who actively scanned the display should do poorly in the dynamic dot detection task. Additionally, it is predicted that participants who use more covert search strategies on tasks that require focal discrimination (e.g., the change blindness task and inefficient search task) will be slower or less accurate than participants who adopt a more overt strategy.

Scanning strategy

As an initial step in analyzing observer's scanning strategy, we calculated the average number of eye movements each participant made per second for each of the four search tasks.¹ This provided a measure of whether participants were overt searchers who tended to make

many eye movements or covert searchers who moved their eyes infrequently. The number of saccades per second was averaged across set sizes for the inefficient and efficient visual search tasks.

First, we examined the relationship between eye movement rate and search performance in the two detection search tasks: the dynamic dot detection and change blindness tasks (see Figure 4). Saccade rate accounted for 62% of the variance in detection accuracy in the dynamic dot detection task ($r = -0.788$, $p < 0.001$), replicating the results of Becic, Kramer, and Boot (2007) and Boot et al. (2006). Additionally, scanning strategy was not significantly correlated with response speed ($r = 0.31$, $p = 0.06$), although there was a trend for participants who scanned more overtly to respond more slowly. Thus in terms of speed and accuracy, it appears that poorer performance in the dynamic dot detection task is associated with a more overt search style. In the change blindness task, eye movement rate accounted for less than 1% of the variance in accuracy of target detection ($r = 0.01$, $p = 0.95$). Similar to the dynamic dot detection task, there was also a trend for scanning rate to influence reaction time. However, this relationship was in

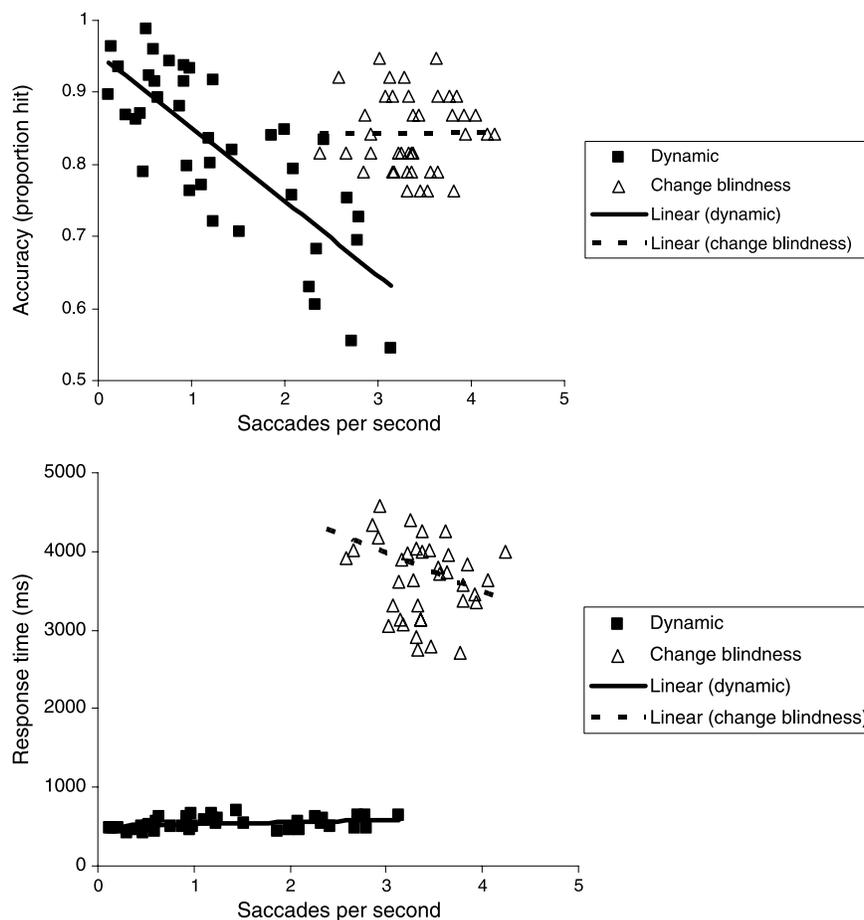


Figure 4. The relationship between saccade rate and the hit rate and response time in the dynamic dot detection and change blindness tasks.

the opposite direction, with overt searchers responding more quickly than covert searchers ($r = -0.29, p = 0.07$). To summarize, a covert scanning strategy was the most optimal strategy in the dynamic dot detection task, and while scanning strategy had less of an impact in the change blindness task a clear trend toward faster response times was found for more overt searchers.

Next, we present the relationship between the number of eye movements and target detection performance in the two static search tasks: the efficient and inefficient search tasks (finding a tilted line among vertical lines and finding a T among Ls, respectively). The correlation between the number of saccades made and the accuracy of detection did not reach significance for either the efficient (*set sizes 4, 8, and 12*: $r = 0.00, p = 0.99, 8: r = -0.13, p = 0.43, 12: r = -0.29, p = 0.07$) or inefficient (*set sizes 4, 8, and 12*: $r = 0.01, p = 0.96, 8: r = 0.14, p = 0.37, 12: r = 0.15, p = 0.37$) visual search tasks (Figure 5). This is not surprising given that performance was near ceiling. Figure 6 presents response time data for each task as a function of saccade rate. For the inefficient search task, there was a relationship between response time and

scanning rate that was statistically significant for at least the small set size, with a trend existing for the other two set sizes as well (*set sizes 4, 8, and 12*: $r = -0.35, p = 0.03, 8: r = -0.30, p = 0.06, 12: r = -0.29, p = 0.07$). Thus, as predicted, the more overtly participants searched for the target, the quicker they found it. Participants who adopted a more covert strategy performed more poorly. For the efficient search task, no such relationship was found (*set sizes 4, 8, and 12*: $r = -0.05, p = 0.76, 8: r = 0.05, p = 0.77, 12: r = 0.01, p = 0.94$).² These data, similar to the change blindness data, suggest that a more overt strategy is preferable (in terms of response speed) when searching for a target that is difficult to detect and that requires focused attention. To summarize, an overt scanning strategy was the most optimal strategy for the inefficient search task while for the efficient search task scanning strategy had no effect.

Stability of scanning strategy

The most important question investigated in the current study relates to the stability of scanning strategy across

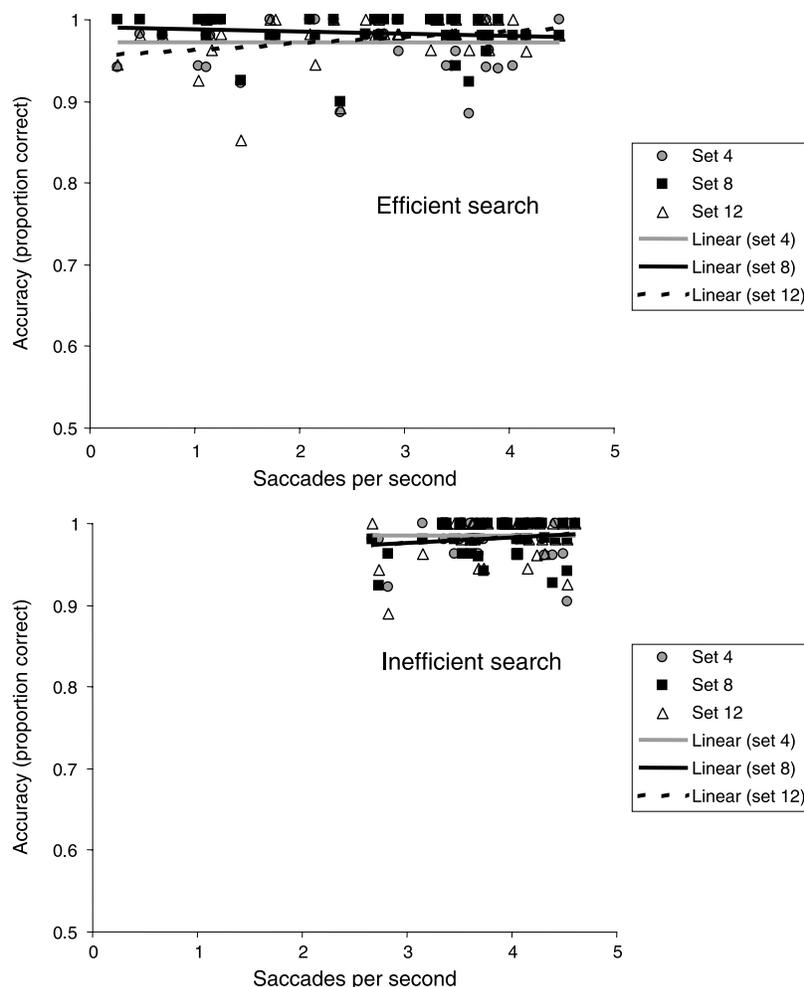


Figure 5. The relationship between saccade rate and accuracy in the efficient and inefficient tasks.

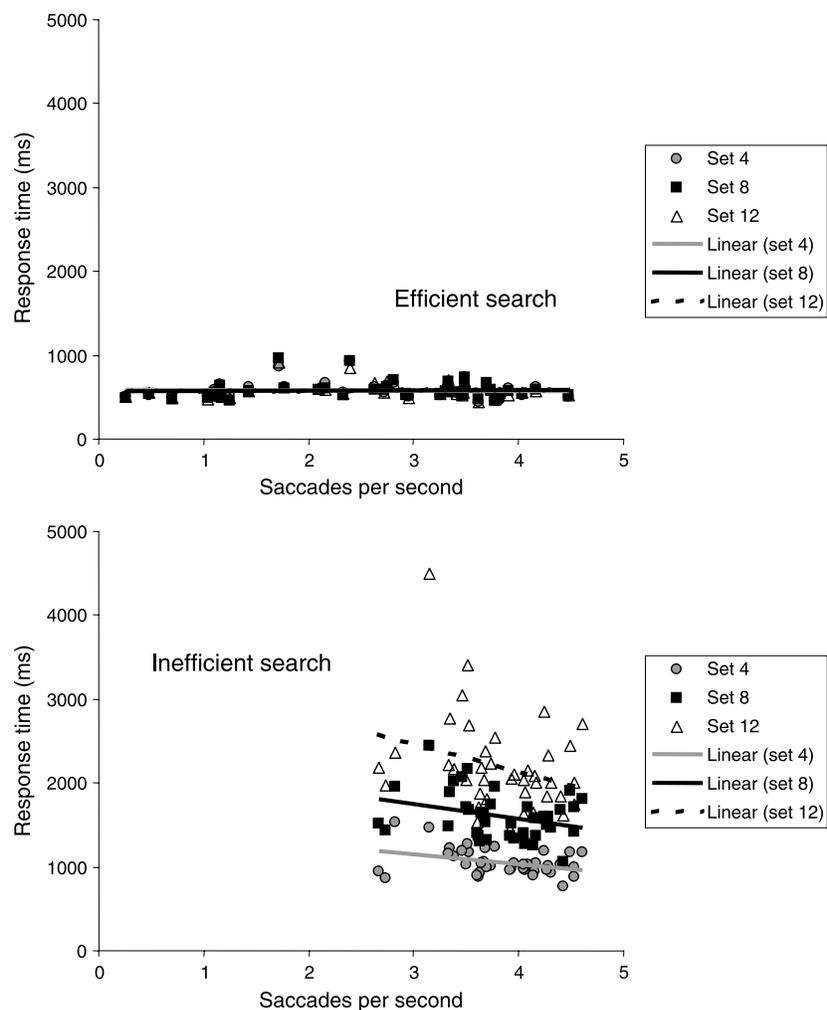


Figure 6. The relationship between saccade rate and response time in the efficient and inefficient tasks.

different tasks in which different strategies can influence performance. In order to answer this question, we investigated the existence of a relationship between participants' strategy across different tasks. Figure 7 represents the scatter plots comparing saccade rate in each task to each other task. All correlations are in a positive direction suggesting that observers retained their scanning strategy across different visual search and change detection tasks. Those observers who made many eye movements in the dynamic dot detection task continued to be active searchers in the static visual search tasks as well as in the change blindness task. It is important to note the correlation between eye movements in the dynamic dot detection task and the inefficient visual search task. This relationship is especially noteworthy since an overt or covert strategy in one task has the opposite effect on performance in the other task, yet participants tended to maintain a similar scanning strategy. The correlation analyses between each task revealed a significant relationship, except in the case of the relationship between the change blindness task and the

dynamic dot detection, and in the relationship between the change blindness task and efficient visual search task.

Order effects

To investigate whether spontaneous selection of scanning strategy was influenced by previous tasks performed we explored the eye movement data for the presence of order effects. One can imagine that a participant might make greater or fewer eye movements during a task if he or she just completed a search task that required a more covert or overt strategy. However, no significant order effects were observed. For example, comparing the number of eye movements participants made in the inefficient and efficient search tasks (which were always completed one after another on the same day) revealed no significant difference in eye movement rate depending on which search task came first. Participants who completed the efficient search task first did not make significantly fewer eye movements compared to participants who completed the inefficient search task first while performing the inefficient search task (3.9 vs. 3.8 saccades per

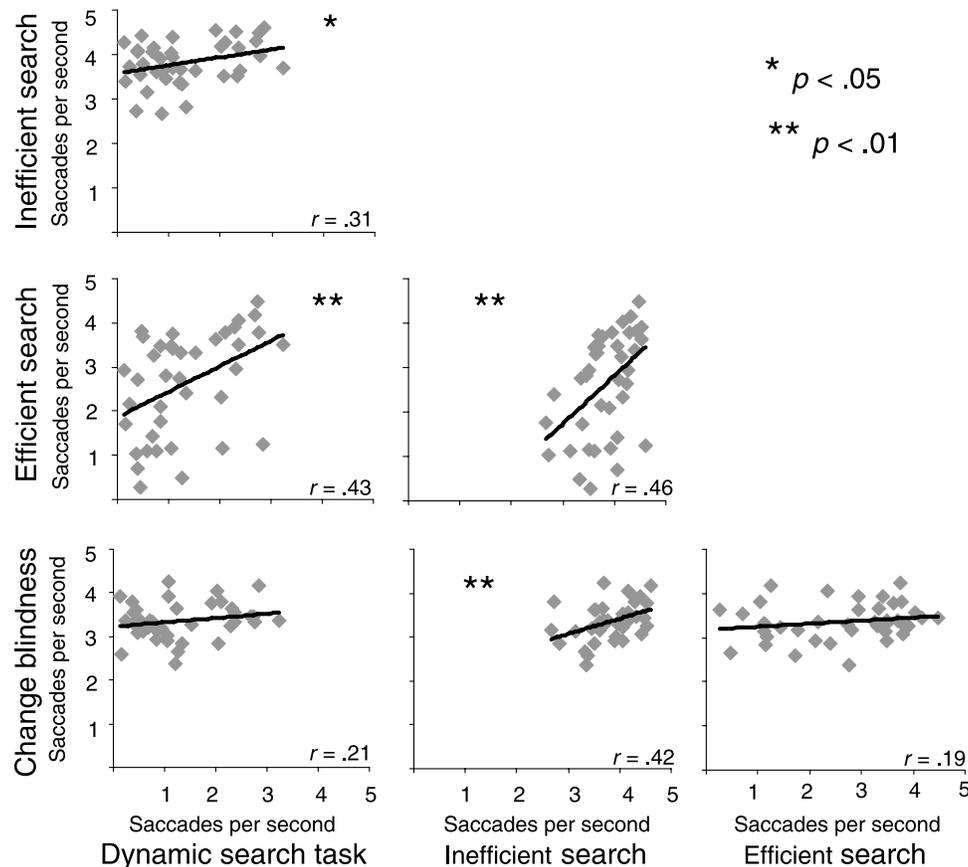


Figure 7. Correlations between saccade rate for each of the four visual search tasks in [Experiment 1](#).

second respectively, $F(1, 38) = 0.49$, $p = 0.50$). Additionally, participants who completed the inefficient search task first did not make significantly more eye movements compared to participants who completed the efficient search task first while performing the efficient search task (2.8 vs. 2.4 saccades per second, $F(1, 38) = 1.13$, $p = 0.29$). As another example, comparing the twenty participants who completed the dynamic dot detection task and the change blindness task on the same day, no significant order effects were observed. Participants who completed the dynamic dot detection task first made greater, not fewer eye movements on average when they performed the change blindness task compared to participants who performed the change blindness task first (3.6 vs. 3.4 saccades per second, $F(1, 18) = 1.24$, $p = 0.28$). One hint of an order effect was observed for participants who completed the change blindness task first, although this effect was not significant. Participants who completed the change blindness task first tended to make more eye movements in the dynamic dot detection task compared to participants who completed that task first (1.6 vs. 0.9, respectively, $F(1, 18) = 3.00$, $p = 0.10$).

To summarize, these results clearly show that observers retain their scanning strategy across different tasks; however, we also presented evidence of adjustment in scanning strategy depending on the task performed. For

example, the distributions of saccade rates in [Figures 4 and 5](#) (efficient and inefficient search) are clearly different. It is clear that the demands of the task are driving to some extent whether participants act in a manner that is more overt or covert. Of a particular interest is the presence of individual variability and whether strategy adjustments observers made across different tasks are uniform or if some observers exhibited greater changes in saccade rate than others. It is certainly reasonable to expect some level of variability in scanning strategy adjustment; however, what effect does increased variability in saccade rate have on overall performance across different tasks? To answer this question we calculated the standard deviation of the number of saccades participants made across the four tasks and averaged the proportion of correct responses across the four tasks. These data revealed a significant relationship between the variability in saccade rate across the tasks and average accuracy ($r = 0.66$, $p < 0.001$). This suggests that while observers do retain their overall scanning strategy, those observers who adjust their scanning strategy to a greater degree exhibit the greatest overall benefit in accuracy. Although not significant, the relationship between response speed and variability in scanning strategy showed a similar trend for faster responses for those participants who adjusted their scanning strategy the most ($r = -0.24$, $p = 0.14$).

Discussion

Experiment 1 demonstrated that participants, when no feedback was given about performance, tended to adopt the same search strategy when presented with a number of different types of search tasks, even when that strategy resulted in slow or inaccurate performance. Although strategy remained similar, task-specific modulation of saccade rate was clearly observed. Participants tended to make fewer saccades in tasks such as the dynamic dot detection task and the efficient search task compared to the change blindness task and the inefficient search task. However, in general, strategy tended to remain similar across tasks.

An interesting and important question is the degree to which similar scan strategies across tasks might be modified by explicit feedback about performance and motivation to change strategy. We and others have demonstrated that participants use the same oculomotor approach in a number of tasks and viewing situations, but do participants modify this approach when it becomes clear that such a strategy is resulting in poor performance? Does saccade rate really represent a stable individual difference? In **Experiment 2**, participants were provided with feedback after each trial, and monetary incentive to ensure feedback would be attended. If participants do not modify their strategy (i.e., strategy is still similar across tasks), this would be evidence of strong, stable individual differences. If participants do change their strategy based on feedback and motivation, this would be evidence that similar strategy across many tasks is a weak preference to utilize one strategy over another under conditions of uncertain performance and low consequences.

Experiment 2

Methods

Participants

Thirty undergraduate students from the University of Illinois at Urbana-Champaign participated in the current study. All participants exhibited normal or corrected-to-normal vision and passed the Ishihara color blindness test. The experiment was completed in one 60-minute session and participants were paid \$8/hour for their participation. The best performer in each of the two tasks participants performed was awarded \$20 of bonus pay.

Apparatus

Apparatus was the same as in **Experiment 1**.

Stimuli and tasks

Participants performed two different search tasks, one that could be performed well without eye movements

(the dynamic dot task), and one that required a more overt strategy (inefficient search). These two tasks were chosen since (1) performance was related to search strategy and (2) the same strategy resulted in opposite effects on performance, requiring a shift in strategy for good performance. The order of tasks was counterbalanced to minimize the influence of order effects.

Dynamic dot detection

The dynamic dot task was the same as in **Experiment 1** except participants were given explicit feedback about accuracy since eye movement rate was most related to accuracy in this task. Feedback was provided after every trial. If participants responded when no target was present, they saw a message reading “INCORRECT: No target present.” If participants did not respond when a target was present, they saw a message reading “INCORRECT: You missed it!” If participants correctly indicated a target was present, they saw a message reading “CORRECT: Target present.” If participants did not respond and no target was present, they saw a message reading “CORRECT: No target present.” Participants were informed that accuracy of detecting the new object was most important in this task and the most accurate participant would receive an additional \$20 in payment.

Inefficient search task

The inefficient search task was the same as in **Experiment 1** except only the large set size (12 items) condition was included. Participants received explicit feedback about speed since eye movement rate was related to speed in this task. Speed feedback was based on the average speed for set size 12 in **Experiment 1** (about 2100 ms). If participants responded prior to 2100 ms, they saw a message reading “You were fast!” If participants responded after 2100 ms, they saw a message reading “A bit slow!” Participants were informed that speed was most important in this task and the fastest participant (who responded accurately) would receive an additional \$20 in payment.

Results

Average accuracy in the dynamic dot detection task was 79% ($SD = 0.09$) and average response time was 509 ms ($SD = 77$). Average accuracy in the inefficient search task was 94% ($SD = 0.09$) and average response time was 1854 ms ($SD = 302$). On average, participants made 1.1 ($SD = 0.91$) saccades/second in the dynamic dot task and 4.2 ($SD = 0.56$) saccades/second in the inefficient search task. Replicating previous work and **Experiment 1**, saccade rate was negatively correlated with accuracy in the dynamic dot task ($r = -0.55, p < 0.01$). Replicating **Experiment 1**,

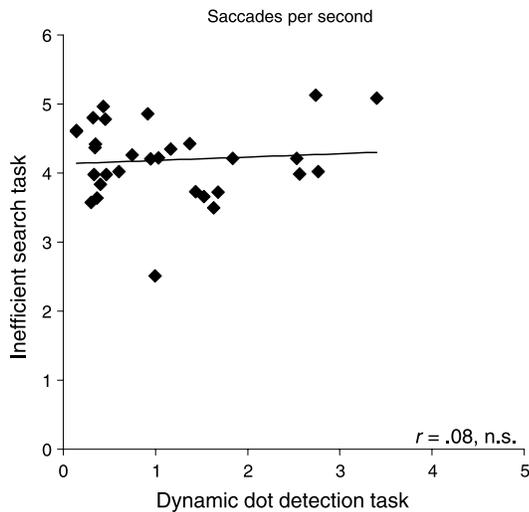


Figure 8. Correlation between saccade rate in the inefficient search task and dynamic dot detection task in [Experiment 2](#).

saccade rate was negatively correlated with response times in the inefficient search task ($r = -0.42$, $p < 0.01$). However, unlike [Experiment 1](#), there was no longer a significant correlation between eye movement strategy between the two tasks ($r = 0.08$, $p = 0.67$, [Figure 8](#)).

Discussion

[Experiment 2](#) confirmed the relationship between eye movement rate and performance for both the dynamic dot detection task and an inefficient search task. In the relevant measures of performance, the same strategy had opposite effects. However, feedback and motivation to attend to that feedback and perform well appeared to cause participants to shift their strategy rather than maintain similar strategies across tasks. Thus, based on situational factors, participants will abandon their default strategy and adopt a strategy that is more adaptive to the task at hand.

General discussion

Boot et al. (2006) have shown a strong relationship between scanning strategy and change detection performance in a dynamic dot detection task that was developed to represent a sonar/radar monitoring task. The scan strategy participants chose could explain up to 73% of the variance in change detection performance, a finding supported by the current study. Moreover, Boot et al. (2006) have shown that observers' scanning strategy can be flexible. Upon simple instructions, observers were able to change their strategy (and as a result, their accuracy) and become either covert or overt searchers. This flexibility has

prompted us to investigate scan strategies across different search tasks and ask whether observers retain idiosyncratic strategies across different tasks and under different conditions of feedback/motivation. These findings indicate that scan strategies do remain stable across a variety of both static and dynamic tasks when the relationship between strategy and performance is unclear or motivation to perform well is low. This may help explain why participants bring poor scan strategies to certain tasks. In [Experiment 1](#), participants who used an overt strategy (i.e., moved their eyes frequently) in the static search tasks (efficient and inefficient search tasks) remained overt searchers in the dynamic dot task even though this strategy was highly detrimental to performance. Besides being stable, scan strategies also appear to be shaped by the task. On average, participants tended to adopt more overt or covert strategies depending on the demands of the visual search task at hand, even without explicit feedback about performance (e.g., compare the distribution of eye movements made by participants performing the inefficient and efficient search tasks in [Figure 5](#)). While there was a relationship between oculomotor behavior in each task, this relationship was far from perfect. Thus participants were modifying their strategy to some extent based purely on the task requirements. Furthermore, it was found that those participants who varied their strategy performed more accurately overall compared to participants who showed less variability across tasks.

Interestingly, the results of [Experiment 2](#) diverged from [Experiment 1](#). While the same relationships between saccade rate and performance were observed, there was no evidence of participants using similar strategies across the tasks. It is possible that under conditions of uncertainty regarding performance (i.e., no feedback), or low motivation (i.e., no incentive to do well), participants utilize a default strategy. It is interesting, however, that even under conditions of feedback and high motivation a large number of participants in the dynamic dot detection task still utilized a highly maladaptive strategy. That is, overt searchers appear to truly believe that the overt strategy is effective, with a number of participants making close to three saccades per second.

The current results connect nicely with the results of Boot et al. (2006). Boot and colleagues explicitly told participants to adopt a maladaptive or an adaptive strategy and feedback was withheld. In general, participants followed the instructions they were given. Notably, even participants who demonstrated the correct strategy in previous sessions were compliant and adopted a maladaptive strategy in subsequent sessions when instructed to do so (since feedback was withheld, it is likely they did not notice any drop in performance). The motivation to adopt one strategy over another strategy in these instruction conditions was simple; participants were told that the instructed strategy would result in quicker and more accurate performance. In other words, the strategy would make their task easier. In the current study ([Experiment 2](#)),

participants were made aware of their own performance. Thus the consequence of a particular strategy could be assessed and participants could adjust their strategy and explore the effects of these strategy shifts on performance. Participants were also motivated to find the most effective strategy for each task. This resulted in an uncoupling of scanning strategy across tasks.

These results confirm, extend, and qualify the findings of Andrews and Coppola (1999), who found stable individual differences in fixation duration and saccade length across similar viewing tasks. They found that eye movement parameters in a number of free-viewing conditions were dissimilar to active viewing conditions such as search and reading. However, eye movement parameters were similar within active viewing conditions, and within passive viewing conditions. Our results show that in addition to task parameters, factors that do not specifically involve changes to task demands (motivation and feedback) can also influence the stability of individual differences. These results are also informative in light of the results of Castelano and Henderson (2008). Over a large number of diverse viewing tasks, eye movement patterns remained stable. An interesting future investigation would be to examine whether individual differences in eye movement parameters in the paradigm of Castelano and Henderson would result in differences in memory performance in a subsequent memory test, and whether instruction could modify eye movement patterns and improve memory performance.

The current results indicate that the same strategy applied to different tasks can have different effects on performance. While an overt strategy tended to allow faster performance in the inefficient search task and change blindness task, this strategy clearly negatively affected performance in the dynamic dot detection task. In the efficient search task, it appears that both strategies are well suited for the task. Why is it that eye movements are harmful to target detection in the dynamic search task? We speculate that it is due to the transient nature of the target. In all other search tasks tested, the target was different from the distractor items on some dimension and this difference persisted in time (a T or titled line target was always different from surrounding distractors, and in the change blindness task the changing target continued to change throughout the trial). However, the item that onset in the dynamic dot detection task was unique only briefly. After its onset, the target item appeared no different from any other item in the display. Thus, if an eye movement caused participants to miss the transient signal from the onset item, it was almost impossible (given the large set size) to tell that one new item was now in the display. This speculation is supported by data indicating that with a smaller set size, the relationship between scan strategy and target detection in this task is decreased (Boot et al., 2006). The fewer items in the display, the easier it is to tell that a new item has been added through means that do not involve detection of a transient signal.

What is the nature of the disruption caused by eye movements in the dynamic dot task? This disruption might come from saccadic suppression, which occurs not only during an eye movement, but slightly before and after an eye movement as well, but it may also be attentional. Given that attention precedes eye movements (Deubel & Schneider, 1996), participants who make many eye movements spend much of the trial with their attention directed to specific locations that are unlikely to be the location of the target. It should be noted that eye movements had a negative effect on response times as well, which might be explained by cases in which an eye movement degrades but does not destroy the transient signal associated with the new dot.

Both of the tasks that we predicted to require a more overt strategy for success showed beneficial eye movement effects in response time measures rather than accuracy (inefficient search, change blindness). This finding seems rather intuitive. When participants move their eyes faster they are more likely to land on the target sooner. However, since the target in these tasks (a portion of a scene undergoing a change again and again or a T facing to the left or the right) continued to persist throughout the trial, errors were unlikely. However, it is obvious that some minimum fixation duration is necessary for targets and distractors to be processed correctly, and a strategy that is too overt (one that does not allow the eyes to remain in one location long enough for successful processing) could have the opposite effect on response time.

Although the data point to the conclusion that participants who used a maladaptive scan strategy in the dynamic dot detection task did so because that is the strategy they bring to many tasks, this still does not answer the question of why this is their default strategy under conditions of uncertainty. The answer to this question is one that the current study cannot provide. It is possible that differences in visual discrimination or attentional abilities influence oculomotor behavior in some search tasks, and that this behavior is carried over into tasks such as the dynamic dot detection task. In support of this hypothesis, Leber and Egeth (2006a, 2006b) demonstrate that prior experience with one type of search task can in fact influence strategy in other similar tasks. As an example, imagine an individual with a fairly restricted functional field of view. He or she might have developed a strategy over many years to direct attention to individual items rather than attempt to process items in the periphery. This might result in an overt search style that becomes the default strategy of this individual. As another example, an airport baggage screener who spends time each day performing a difficult search task that requires many overt fixations on potential target items might be more likely to choose an overt strategy in other unrelated tasks. Conversely, expert video game players typically demonstrate an expanded functional field of view (Green & Bavelier, 2003). Frequent playing of video games that encourage diffuse attention might encourage

gamers to be more likely to utilize a covert search strategy. Future studies could investigate whether individual differences in employment or hobbies influence whether participants choose a more overt or covert search strategy by default. Finally, these differences may be the result of individual differences in the structure and function of various brain regions known to control endogenous eye movements (e.g., Butler, Zacks, & Henderson, 1999; Nigg, Butler, Huang-Pollock, & Henderson, 2002). It is possible that neuroimaging, especially imaging while participants are not actively engaged in a visual task, might reveal something about the default state of the eye movement system that might contribute to these individual differences (Greicius, Krasnow, Reiss, & Menon, 2003). Although we demonstrate here that strategies covary across tasks, it is still an open question as to why a participant might choose to adopt one strategy over another as their default strategy.

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Footnotes

¹Eye movement rate rather than fixation duration was analyzed to be consistent with previous studies using the dynamic dot detection task of primary interest here. Intuitively it is clear that these measures are highly correlated. Given that some participants rarely moved their eyes while performing certain tasks, and that eye movements made by these participants seemed largely fixational in nature, a clear interpretation of saccade amplitude could not be made in the current data sets.

²Although not a significant effect, there was a suggestion that overall saccade rate might be related to search efficiency (i.e., slope), with more eye movements resulting in shallower slopes in the inefficient search task ($r = -0.24$, $p = 0.14$). There was no suggestion of a relationship in the efficient search task ($r = 0.03$, $p = 0.85$).

References

- Andrews, T. J., & Coppola, D. M. (1999). Idiosyncratic characteristics of saccadic eye movements when viewing different visual environments. *Vision Research*, *39*, 2947–2953. [PubMed]
- Araujo, C., Kowler, E., & Pavel, M. (2001). Eye movements during visual search: The costs of choosing the optimal path. *Vision Research*, *41*, 3613–3625. [PubMed]
- Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science*, *34*, 3110–3123. [PubMed] [Article]
- Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America A, Optics and Image Science*, *5*, 2210–2219. [PubMed]
- Becic, E., Kramer, A. F., & Boot, W. R. (2007). Age-related differences in visual search in dynamic displays. *Psychology and Aging*, *22*, 67–74. [PubMed]
- Bellenkes, A. H., Wickens, C. D., & Kramer, A. F. (1997). Visual scanning and pilot expertise: The role of attentional flexibility and mental model development. *Aviation, Space, and Environmental Medicine*, *68*, 569–579. [PubMed]
- Boot, W. R., Kramer, A. F., Becic, E., Wiegmann, D. A., & Kubose, T. (2006). Detecting transient changes in dynamic displays: The more you look, the less you see. *Human Factors*, *48*, 759–773. [PubMed]
- Boot, W. R., McCarley, J. S., Kramer, A. F., & Peterson, M. S. (2004). Automatic and intentional memory processes in visual search. *Psychonomic Bulletin & Review*, *5*, 854–861. [PubMed]
- Brockmole, J. R., & Henderson, J. M. (2006). Using real-world scenes as contextual cues during search. *Visual Cognition*, *13*, 99–108.
- Butler, K. M., Zacks, R. T., & Henderson, J. M. (1999). Suppression of reflexive saccades in younger and older adults: Age comparisons on an antisaccade task. *Memory & Cognition*, *27*, 584–591. [PubMed]
- Castelhano, M. S., & Henderson, J. M. (2008). Stable individual differences across images in human saccadic eye movements. *Canadian Journal of Experimental Psychology*, *62*, 1–14. [PubMed]
- Christ, S. E., & Abrams, R. A. (2006). Abrupt onsets cannot be ignored. *Psychonomic Bulletin and Review*, *13*, 875–880. [PubMed]
- Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, *36*, 1827–1837. [PubMed]
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental*

- Psychology: Human Perception and Performance*, 18, 1030–1044. [PubMed]
- Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 317–329. [PubMed]
- Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, 423, 534–537. [PubMed]
- Greicius, M. D., Krasnow, B., Reiss, A. L., & Menon, V. (2003). Functional connectivity in the resting brain: A network analysis of the default mode hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, 100, 253–258. [PubMed] [Article]
- Heinke, D., Humphreys, G. W., & Tweed, C. L. (2006). Top-down guidance of visual search: A computational account. *Visual Cognition*, 14, 985–1005.
- Henderson, J. M., Brockmole, J. R., Castelano, M. S., & Mack, M. (2007). Visual saliency does not account for eye movements during search in real-world scenes. In R. van Gompel, M. Fischer, W. Murray, & R. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 537–562). Oxford: Elsevier.
- Henderson, J. M., & Hollingworth, A. (1999). The role of fixation position in detecting scene changes across saccades. *Psychological Science*, 10, 438–443.
- Itti, L. (2006). Quantitative modelling of perceptual salience at human eye position. *Visual Cognition*, 14, 959–984.
- Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, 40, 1489–1506. [PubMed]
- Law, B., Atkins, M. S., Kirkpatrick, A. E., Lomax, A. J., & Mackenzie, C. L. (2004). Eye gaze patterns differentiate novice and experts in a virtual laparoscopic surgery training environment. In: Duchowski, A., Vertegan, R. (co-chairs). *Proceedings of the 2004 Symposium on Eye Tracking Research and Applications* (pp. 41–48). San Antonio, TX: Assoc for Computing Machinery.
- Leber, A. B., & Egeth, H. E. (2006a). Attention on autopilot: Past experience and attentional set. *Visual Cognition*, 14, 565–583.
- Leber, A. B., & Egeth, H. E. (2006b). It's under control: Top-down search strategies can override attentional capture. *Psychonomic Bulletin & Review*, 13, 132–138. [PubMed]
- McCarley, J. S., Vais, M. J., Pringle, H., Kramer, A. F., Irwin, D. E., & Strayer, D. L. (2004). Conversation disrupts change detection in complex traffic scenes. *Human Factors*, 46, 424–436. [PubMed]
- Nigg, J. T., Butler, K. M., Huang-Pollock, C. L., & Henderson, J. M. (2002). Inhibitory processes in adults with persistent childhood onset ADHD. *Journal of Consulting and Clinical Psychology*, 70, 153–157. [PubMed]
- Peterson, M. S., & Kramer, A. F. (2001). Contextual cueing reduces interference from task-irrelevant onset distractors. *Visual Cognition*, 8, 843–859.
- Pringle, H., Irwin, D. E., Kramer, A. F., & Atchley, P. (2001). Relationship between attention and perceptual change detection in driving scenes. *Psychonomic Bulletin and Review*, 8, 89–95.
- Rayner, K., Xingshan, L., Williams, C. C., Cave, K. R., & Well, A. D. (2007). Eye movements during information processing tasks: Individual differences and cultural effects. *Vision Research*, 47, 2714–2726. [PubMed] [Article]
- Rendell, M., & Morgan, S.W. (2005). Skill and role-specific differences in eye movement behaviour between goal keepers and field players in field hockey. *International Journal of Performance Analysis in Sport*, 5, 163–167.
- Ross, J., Morrone, M. C., Goldberg, M. E., & Burr, D. C. (2001). Changes in visual perception at the time of saccades. *Trends in Neurosciences*, 24, 113–121. [PubMed]
- Savelsbergh, G. J. P., Williams, A. M., van der Kamp, J., & Ward, P. (2002). Visual search, anticipation, and expertise in soccer goalkeepers. *Journal of Sports Science*, 20, 279–287.
- Simons, D. J., & Ambinder (2005). Change blindness: Theory and consequences. *Current Directions in Psychological Science*, 14, 44–48.
- Smilek, D., Enns, J. T., Eastwood, J. D., & Merikle, P. M. (2006). Relax! Cognitive strategy influences visual search. *Visual Cognition*, 14, 534–564.
- Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 799–806. [PubMed]
- Theeuwes, J., & Burger, R. (1998). Attentional control during visual search: The effect of irrelevant singletons. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 1342–1353. [PubMed]
- Theeuwes, J., Kramer, A. F., Hahn, S., Irwin, D. E., & Zelinsky, G. J. (1999). Influence of attentional capture on oculomotor control. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 1595–1608. [PubMed]

- Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review*, *1*, 202–238.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601–621. [[PubMed](#)]
- 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. [[PubMed](#)]