

Are Eye Movements Involved in Cued Target Recall from Repeating Spatial Contexts?

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Abstract

Across two experiments we set out to determine if visual scans adapt to repeatedly searched stimuli. We adopt a paradigm reported to produce cueing effects from repeatedly searching the same stimulus (Chun & Jiang, 1998). We discover that eye movements may be useful to the cueing process, and that the cueing phenomenon is finicky.

Keywords: visual scanning, scanpath, contextual cueing, rational analysis, soft constraints

Introduction

Every day, humans actively access information from their visual environment. A visual stimulus, such as a kitchen counter, may be examined hundreds of times with short delays (minutes or hours) or long delays (days or weeks) between each viewing. Examinations can be broken into instances where the eyes are relatively stable (*dwells*) and when they move at high velocities (*saccades*). Task goals, such as making a sandwich (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003), have been demonstrated to affect the distributions of dwell locations and dwell durations. Consequently, ocular behavior can result from *endogenous processes* influencing the eyes where and when to acquire task-relevant information.

Research has also demonstrated that ocular behavior is affected by environmental nuances. Such effects result from *exogenous processes* – the environment influences the eyes to particular locations. Exogenous processing is facilitated by the salience of stimulus features that compose the visual environment, where salient stimuli attract attention, constraining the order of information visited through stimulus-driven eye movements (Franconeri, Simons, & Junge, 2004; Theeuwes, 2004).

Several lines of research across several disciplines have addressed the interaction between human cognition and the task environment (for a summary see Gray, Neth, & Schoelles, in press). For example, Anderson's rational analysis (1990) suggests a cost-benefit tradeoff during human-environment interactions. Rational analysis is an analytical approach to understanding the mediation between cognitive and environmental influences, and asserts that much of human cognition is adapted to the statistical structure of the task environment. Gray's soft constraints theory (Gray, Sims, Fu, & Schoelles, 2006) applies the rational analysis framework to the 1/3 s level of behavior, or the *embodiment level* (Ballard, Hayhoe, Pook, & Rao, 1997), and predicts the scheduling of eye movements,

manual motor movements, and memory retrievals during interactive behavior.

Soft constraints theory provides an approach to understanding how endogenous and exogenous influences are mediated, and can be interpreted as predicting efficiency gains in patterns of visual search across repeated experience with the same visual stimulus/goal combination. Indeed, recent research indicates that the cost of a single dwell-saccade pair is eliminated from behavior when it does not reliably lead to the task goal, as predicted by soft constraint theory (Myers & Gray, submitted).

Consistent Sequences of Eye Movements

Previous research has demonstrated that dwell-saccade sequences can become relatively consistent across repeated scans of the same stimulus, forming stable visual scans. Stable scans are hypothesized to take the form of proceduralized sequences of saccades stored in memory rather than successions of individually programmed eye movements (Noton & Stark, 1971). Consequently, stable scans are hypothesized to result directly from endogenous processes (Grosbras et al., 2001; Josephson & Holmes, 2002).

Understanding visual scanning requires an *active vision* approach to understanding ocular behavior as opposed to the *passive vision* approach. The active vision approach advocates understanding vision via understanding the fovea and movements of the eye while the passive vision approach fundamentally discounts saccades and dwells from explanations and theories of ocular behavior (Findlay & Gilchrist, 2003). Because the passive approach to vision has dominated much of the reported research in visual cognition, little is known about scanning behavior or its contribution to visual and perceptual phenomena. However, the research that has been reported on visual scanning demonstrates that stable scans occur on repeated visual stimuli and are mostly idiosyncratic (Zangemeister, Sherman, & Stark, 1995) but can be similar between participants (Josephson & Holmes, 2002), are important to recalling imagined items (Laeng & Teodorescu, 2002), and have been correlated to neural structures that differ to the neural structures involved in executing a novel sequence of saccades (Grosbras et al., 2001).

A critical limitation to understanding visual scanning is that a majority of the reported research has been conducted using a free-view paradigm – participants are allowed to freely view a stimulus with instructions amounting to

“remember this image.” The current research extends the understanding of visual scanning from a free-view paradigm to goal-oriented tasks. Furthermore, previously reported research demonstrates that visual scans obtained with a free-view paradigm are stable across multiple views of the same stimulus, and are thus just like any other sequential motor skill, making them subject to memory mechanisms and proceduralization. Theories of behavioral refinement (e.g., soft constraints theory) state that behavior is adjusted to reduce cost in units of time during goal-oriented tasks. Consequently, it is likely that visual scans repeatedly used during a goal-oriented task are adapted to the environment through some refinement mechanism. Such an adaptation could occur by reducing the number of eye movements necessary to obtain the goal over repeated exposures to the same stimulus. Finally, it is possible that the two hypotheses just presented are the mechanism behind the contextual cueing phenomenon, elaborated in the following section.

The Contextual Cueing Phenomenon

Previous research has demonstrated that visual context implicitly guides spatial attention during visual search tasks (Chun & Jiang, 1998; Song & Jiang, 2005). Chun, Jiang, and colleagues operationally define context as the relative visuospatial arrangement of items composing a stimulus. Research on how visual context affects visual search has demonstrated that multiple searches through repeating contexts improves search times beyond regular motor speed-up of practiced skills (see Figure 1). Chun, Jiang, and colleagues contend that memory for visual context is instance based and implicitly learned across repeated exposures to the same context. Consequently, search improvements result from an implicit context-target pairing, leading to the context cueing the target location. A target location is cued when the current context reaches a similarity threshold with another, previously encoded, context stored in memory. When the similarity threshold is reached, the instance is retrieved from memory and its paired target location directs attention to that location in the current context. Indeed, the hypothesized mechanism, rooted in the passive vision approach, eliminates the need for eye movements to acquire contextual cueing effects.

Although contextual cueing has been documented and its underlying processes alluded to across several studies (Chun & Jiang, 1998; Jiang & Wagner, 2004; Peterson & Kramer, 2001), there remains room for an active vision account of contextual cueing effects. Contextual cueing is a functional adaptation to the task environment, and likely results from mechanisms that function to minimize cost, in units of time, at the task level (Gray et al. 2006; Myers & Gray, submitted). Repeated visual scans are hypothesized to *trigger* contextual cueing phenomena—eye movements as the similarity metric assumed to occur in memory. Proceduralized visual scans may not be enough to obtain response times similar to those associated with contextual cueing. In this case, refining visual scans by eliminating some dwell-saccade pairs would be necessary (Myers &

Gray, submitted). Refinement would occur through a mechanism that influences the scheduling of behaviors to reduce the cost associated with a task while maintaining accuracy, hypothesized by soft constraints theory.

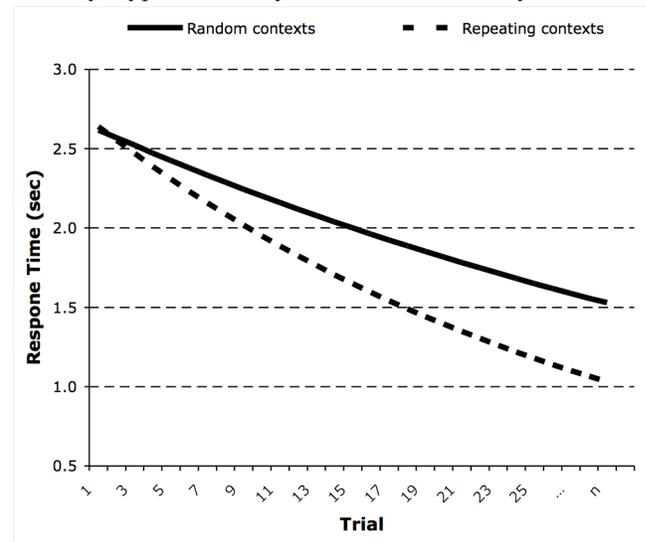


Figure 1. Prototypical contextual cueing effect.

Summary

Although the contextual cueing phenomenon has been documented in several studies, an explicit mechanistic account rooted in the active vision approach remains absent from explanations of contextual cueing effects. We report the results from investigating an active vision approach to understanding contextual cueing. This approach is based on the notions that eye movements are functional and that contextual cueing is a functional adaptation to the statistical structure of the task environment.

Experiments

Two experiments were conducted to determine if eye movements are associated with contextual cueing and if scans adapt to repeatedly searched stimuli. Experiment 1 slightly modifies the procedures from Chun & Jiang’s (1998) fifth experiment, which they used to demonstrate the presence of contextual cueing without eye movements, but fails to replicate their results. In experiment 1 we add to their controls in an added between-participant condition. Experiment 2 explores the refinement of visual scans in the typical contextual cueing paradigm.

Experiment 1 – The Necessity of Eye Movements

Experiment 1 is a test of Chun and Jiang’s (1998) assertion that “contextual cueing can be obtained without eye movements” (p. 56).

Method Used By Chun & Jiang (1998)

In experiment 5 from Chun & Jiang (1998), participants were instructed to find a rotated target (T) among rotated distractors (L) and respond to the target’s direction (right or left). Participants performed a total of 32 blocks of 24 trials per block (768 trials). Blocks were divided into three

phases: training, testing-practice, and testing. Participants completed 20 blocks in the training phase, 2 blocks in the testing-practice phase, and 10 blocks in the testing phase. Within a block, all stimulus configurations were unique, however, across blocks, 12 configurations repeated. Thus, during the training phase participants viewed 12 repeating stimulus configurations 20 times each, and 240 random stimulus configurations once each.

Because repeating configurations were the same spatial arrangement across blocks and because the target was always located in the same location within a repeating configuration, participants could learn target locations. To ensure that any search benefit of repeating configurations was not attributable to learning target location probabilities, 12 target locations were also used for the random configurations. Thus, when a random configuration trial occurred within a block, a target location was randomly sampled without replacement from a set of target locations used for creating random configurations. After target location selection, the distractor locations (11 total) were randomly assigned around the picked target location. Consequently any benefit in repeating configurations cannot be attributable to a small set of possible target locations in repeating configurations (12).

Three displays composed a single trial during the training phase: a dwell control display, a stimulus display, and a feedback display. Participants were instructed to dwell a small dot on the dwell control display for 500 ms. Next, the stimulus was displayed until a response was issued. After the response, a blank screen was displayed and accuracy feedback was provided. The feedback display remained for 1 sec and was then replaced by a dwell control display signaling a new trial. Chun and Jiang (1998) report that participants demonstrated a contextual cueing effect by the end of the training phase.

During the testing-practice and testing phases, four displays composed a single trial. Each trial began with a dwell control display for 600 ms followed by the stimulus. After 200 ms the stimulus was replaced with a blank screen that remained present until the participant responded with the rotation of the target. Following a response, accuracy feedback was presented with tones signaling either correct or incorrect responses. After 1 second, the dwell control display reappeared signaling a new trial. In the testing-practice phase, participants completed 2 blocks of trials where all trials were random configurations. In the testing phase, participants completed 240 trials.

The key comparison of the testing phase was the accuracy levels between repeated and random configurations. Chun & Jiang report that participants demonstrated a significant 5% increase in accuracy for repeated configurations (78.5%) when compared to random configurations (73.5%).

Method Used in Experiment 1

The current experiment uses a modified version of Chun and Jiang's (1998) method (*free-view*) and adds a second between-participants condition (*fixed-view*) that further

controls for eye movements throughout a trial and presents masks during feedback.

There were two slight differences between our training phase and Chun & Jiang's. First, the item on the dwell control display was a set of crosshairs rather than a single dot. Second, the crosshairs were gaze contingent: changing from green to red when participants' gaze moved from the crosshairs, and changing back to green when participants' gaze returned. Gaze contingency was used to provide real-time feedback of participants' gaze locations to help ensure all participants' began all trials from the same location. All participants completed the same training phase and were then randomly transferred into either the free-view testing phase or the fixed-view testing phase. Both testing phases began with a testing-practice phase composed of 2 blocks of random configuration trials, as in Chun & Jiang (1998).

The free-view testing phase condition was a slightly modified version of Chun & Jiang's. The two differences were that the dwell control item on the dwell control display was a set of crosshairs rather than a single dot, and the crosshairs were gaze contingent, as in the training phase.

The fixed-view testing phase condition differed considerably from Chun & Jiang's testing phase in two important ways. First, gaze-contingent crosshairs were present on *all displays* in our fixed-view condition. This helped to further ensure eye movements did not occur at anytime throughout a trial. Second, a visual mask was also presented at the same time the feedback display was presented.

If eye movements are unnecessary for contextual cueing to occur, both the free-view and fixed view conditions should replicate Chun & Jiang's (1998, experiment 5) results.

Participants. A total of forty-two undergraduate students consented to participate. All participants had normal, or corrected-to-normal vision.

Apparatus. The data collection apparatus consisted of an Apple G4 computer running MacOS 10.4, a 17-inch flat panel display with the resolution set to 1280 x 1024, a chinrest to promote head stability, and an Eyegaze binocular, video-based remote eye-tracking system developed by LC Technologies that measured point of gaze at a 120Hz rate. Items composing a stimulus subtended 2° of visual angle at a viewing distance of ≈ 56 cm. The Eyegaze system tracking error was 0.63 cm, or less.

Results

Trial data were averaged at the epoch level (1 epoch = 5 blocks = 120 trials) for increased statistical power. Prior to analyses, 2 participants were removed as outliers on response times from the training and testing phases.

Training Phase. Following from Chun and Jiang's analyses, a 2x(2x2) transfer-type (free-view, fixed-view) x [epoch (1,4) x configuration-type (repeating, random)] mixed ANOVA was performed on response times from correct trials. There was a significant configuration-type x epoch interaction on response times, with repeating configuration response times decreasing at a faster rate than

random configurations from epoch 1 to epoch 4, signifying a contextual cueing effect, $F(1, 38) = 4.6, p = 0.038$. Importantly, there was not a significant main effect of transfer-type, $F(1, 38) = 1.0, p > 0.32, NS$, nor was there a significant 3-way interaction of transfer-type, configuration-type and epoch, indicating that the transfer conditions did not interact with contextual cueing, $F(1, 38) = 0.04, p > 0.83, NS$. There were no significant effects associated with accuracy, which was a correct response average of 98.2%.

Testing Phase. As in the training phase, trials were accumulated into epochs, where an epoch was 120 trials.

The dependent variable of interest during this phase is the proportion of correct responses; consequently, correct and incorrect trials were included. A $2 \times (2 \times 2)$ transfer-type (free-view, fixed-view) \times [epoch (5, 6) \times configuration-type (repeating, random)] mixed ANOVA was performed on the proportion of correct trials. The transfer-type \times epoch \times configuration-type interaction from the omnibus ANOVA was not significant, $F(1, 38) = 0.994, p > 0.32, NS$. However, there was a significant epoch \times configuration-type interaction, $F(1, 38) = 4.327, p = 0.044$, where responses to repeating configurations became more accurate from epoch 5 ($M = 0.72$) to epoch 6 ($M = 0.73$), whereas random configurations became less accurate from epoch 5 ($M = 0.75$) to epoch 6 ($M = 0.72$) (see Figure 2). Most importantly, whereas Chun and Jiang found a significant main effect of configuration-type, we did not, $M_{\text{repeating}} = 0.74, M_{\text{random}} = 0.73; F(1, 38) = 0.89, p > 0.35, NS$.

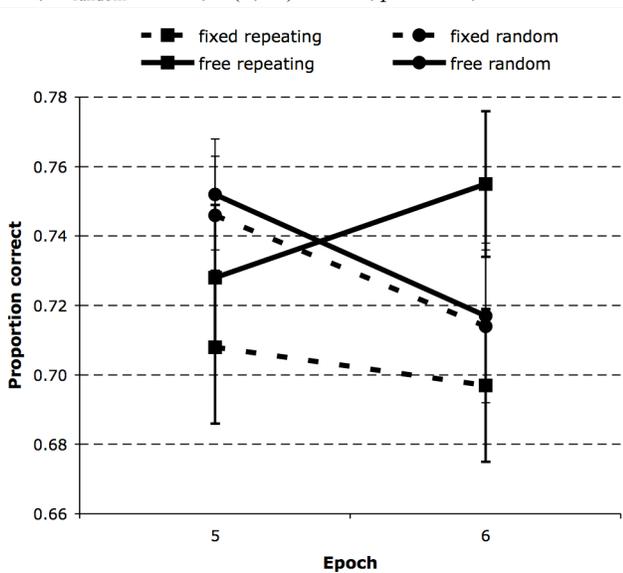


Figure 2. Test Trial Results. Configuration-type (repeating, random) by epoch (5, 6) interaction on proportion of correct trials during the free-view and fixed-view testing phase.

Of particular interest was whether transferring to a fixed-view condition inhibited response accuracy below that from the free-view condition. Although the transfer-type \times epoch \times configuration-type interaction was not significant in the omnibus ANOVA, an epoch (5, 6) \times configuration-type

(repeating, random) mixed ANOVA was performed on the proportion of correct trials for the free-view and fixed-view conditions, separately. There was not a significant configuration-type by epoch interaction, $F(1, 20) = 0.65, p > 0.4, NS$. However, in the fixed-view condition there was a marginally significant effect of configuration-type, $F(1, 18) = 3.91, p = 0.064$, where random stimulus configurations ($M_{\text{random}} = 0.73$) lead to a higher proportion of correct trials when compared to repeating stimulus configurations ($M_{\text{repeating}} = 0.70$) (see Figure 2) – just the opposite of what was found in Chun & Jiang, experiment 5 (1998). Finally, a transfer-type (fixed-view, free-view) \times epoch (5, 6) mixed ANOVA was performed on the proportion of correct trials from repeating configurations during the testing phase to determine if there were any differences in accuracy based on our increased eye movement controls (fixed-view) when compared to relatively relaxed controls (free-view). There was a marginally significant effect of, $F(1, 40) = 3.327, p = 0.076$. Furthermore, note that the random configuration accuracy results from the testing phases of both conditions are nearly identical to Chun & Jiang’s results of 0.735.

Experiment 1 Conclusions

There are three key points to make. First, contextual cueing was established by the end of the training phase, just as Chun & Jiang (1998). Second, we did not replicate Chun and Jiang’s testing phase accuracy results in the condition most closely similar to their experiment 5 experiment methods (free-view): repeating configurations were no more likely to result in a correct response than random configurations. Third, the condition with extra eye movement controls (fixed-view) resulted in lower response accuracy for repeating configurations than random configurations – following what would be predicted if eye movements play a role in cueing target locations.

We hypothesize that our free-view condition did not replicate Chun & Jiang’s results on account of the gaze contingent crosshairs acting as a subtle, yet reliable, dwell control beyond that used by Chun and Jiang (a black dot). Experiments are currently underway test this hypothesis, but will not be reported in the current manuscript.

These results support previous work suggesting that eye movements are more than epiphenomenal, such as playing a functional role during the recall of visual information (Laeng & Teodorescu, 2002). This was demonstrated in experiment 1 as a decrease in response accuracy with increased eye movement controls as evidenced when comparing free-view and fixed-view accuracy results in the testing phase of experiment 1. Indeed, these results suggest that eye movements play a functional role in implicitly cueing target locations within repeating configurations.

Experiment 2 – The Refinement of Visual Scans

The soft constraints hypothesis predicts that behavior adapts to environmental regularities within a task, resulting in a reduction of task completion time (Gray et al. 2006). The contextual cueing phenomenon is a case in point – when the environment provides stable cues for acquiring the target

location, the cognitive system exploits this stability, leading to quicker response times for repeating configurations, as in Figure 1. Myers and Gray (submitted) have demonstrated that unnecessary saccades are avoided to reduce search time, demonstrating search behavior can be refined to reduce costs, in units of time, associated with extraneous saccades and their resultant dwells.

Based on experiment 1 results which suggest that eye movements are useful during contextual cueing, experiment 2 was designed to (a) determine if visual scans are reused across multiple instances of repeated stimuli, (b) to determine if the reused visual scans are refined to decrease response times through the elimination of saccades and dwells, and (c) to determine if there is visual scan similarity between participants on the same stimuli.

Method

Paradigm. The design was a 3 (configuration-group) x [2(configuration-type) x 6(epoch)] mixed design. The task environment contained three key differences from experiment 1. First, items composing each stimulus were reduced in size from 2° of visual angle in experiment 1 to 0.25° in experiment 2. This served to reduce the number of dwells between stimulus items that were near one another. Second, there was no speeded-response testing phase as in experiment 1; instead, all participants performed 720 trials following the same structure as the training phase of experiment 1. Third, participants were given the same set of 24 target locations for repeating and random configurations. However, repeating configurations differed between 3 groups of 5 participants¹. This allowed us to determine if different people scanned the same repeating configuration in a similar manner. Target locations were determined randomly with the constraint that locations must be at least 4° of visual angle from all target locations and the dwell control crosshairs. Importantly, a two-sample t-test on target location distance from dwell control crosshairs did not reveal a difference between repeating and random configuration target locations [$t(22) = -1.13, p > 0.25$].

Participants. A total of 15 undergraduate students consented to participate. All participants had normal, or corrected-to-normal vision.

Apparatus. The data collection apparatus was the same used in experiment 1, except items composing a stimulus now subtended 0.25° of visual angle at a viewing distance of ≈ 56 cm to facilitate visual scan analyses.

Procedure. Participants completed 360 trials, took a 5-minute break, and finished the experiment by completing the remaining 360 trials. The study lasted approximately 1.5 hours. Participants were run individually and compensated for their time.

¹ We did not intend to conduct statistical tests between configuration-groups, as a sample size of 5 is not powerful enough to detect reliable differences. Rather, we wanted to ensure ourselves that there was not something special about a single set of repeating configurations if repeating configurations were scanned in a similar manner between participants.

Results

Trial data were averaged into epochs for increased statistical power, where 1 epoch = 5 blocks = 120 trials, just as experiment 1.

Response Time Analyses. One participant was removed from analyses as a response time outlier, leaving 14 participants for analysis. An epoch (1-6) by configuration-type (repeating, random) repeated-measures ANOVA was performed on correct trials to determine if participants were contextually cued. To our dismay, there was not an epoch by configuration-type interaction, $F(5, 55) = 0.877, p > 0.5, NS$, indicating participants *were not* contextually cued. There was a main effect of epoch, $F(5, 55) = 32.15, p < 0.001$, where response times decreased from epoch 1 ($M_{epoch-1} = 1988.23$ ms) to epoch 6 ($M_{epoch-6} = 1605.5$ ms). The main effect of configuration-type was not significant ($p > 0.5, NS$).

Eye Data Analyses. ProtoMatch software (Myers & Schoelles, 2005) was used to determine dwells and their durations, assign items to dwells, and objectively compare the similarity between visual scans. Two additional participants were removed from the analyses due to poor eye data throughout the experiment. Only correct trials were analyzed. Whereas, there were no effects on dwell duration, the number of dwells to find a target significantly decreased across epochs from a mean of 6 in epoch 1 to a mean of 4.6 in epoch 6, $F(5, 55) = 13.608, p < 0.001$. This effect did not interact with configuration type, $F(5, 55) = 1.67, p > 0.14, NS$. The mean number of times an item was examined more than once during a trial also reduced across epochs from a mean of 0.37 in epoch 1 to a mean of 0.13 in epoch 6, $F(5, 55) = 14.94, p < 0.001$, and did not interact with configuration type, $F(5, 55) = 1.26, p > 0.29, NS$.

Strategy Analyses. The objective of experiment 2 was to determine if visual scans are reused across multiple instances of repeated stimuli, to determine if the reused visual scans are refined to decrease response times through the elimination of saccades and dwells, and to determine if there is visual scan homogeneity between participants.

Unfortunately, rather than analyzing the similarities between visual scans, we attempted to determine why contextual cueing did not replicate. One possibility is that participants overrode contextual cueing with a different search strategy employable on any stimulus configuration. One candidate strategy is to begin at the stimulus display's center, and then search outward examining items until the target is found. If participants searched in this manner, there should be a significant positive correlation between target locations' distance from the crosshairs on the fixation control display and response times. Indeed, there was a positive correlation ($r^2 = 0.61$) that was significantly different from zero, $t(13) = 6.853, p < 0.001$.

Experiment 2 Conclusions

We began by inspecting configuration-types across response time and dwell analyses, but found no evidence of contextual cueing. We next checked to see if a simple

strategy was used, namely starting in the center of the stimulus display and scanning outward. The center-out scanning strategy appears to be how most participants searched for the target, but does not explain why contextual cueing did not occur. A possibility for the absence of contextual cueing in experiment 2 may result from a change in the size of items composing a stimulus, which were reduced from 2° of visual angle in experiment 1 to 0.25° in experiment 2. Neither the contextual mechanism hypothesized in the current paper, nor the mechanism proposed by Chun and Jiang (1998) predict an effect of item size and merits testing.

Discussion

Visual scanning is a ubiquitous activity – we all do it each time we look for our lost file on our computer desktop. Research on visual scanning has demonstrated that scans can be stored in memory and used at later times, such as when recalling information about imagined stimuli (Laeng & Teodorescu, 2002). After searching and finding your missing file on your computer's desktop once, it is likely you'll search in much the same way the second time you lose the file.

The evolution of visual scans across multiple searches through the same stimulus was what we set out to test, and the contextual cueing paradigm lent itself directly to testing visual scan adaptations. Moreover, visual scan adaptations provide a likely explanation for the contextual cueing phenomenon. Indeed, in experiment 1 we found that limiting eye movements during a testing phase hampers accuracy for repeating configurations while not affecting random configurations. Experiment 2 was setup to visual scans were stabilized and refined across repeated exposures to repeating stimuli. However, we were unable to obtain contextual cueing effects when items composing a stimulus were small ($\approx 0.25^\circ$ of visual angle) suggesting that the phenomenon is much more volatile than originally reported.

Across two experiments we demonstrate both the presence and absence of a phenomena that has been replicated in many publications (see Lleras & Von Muhlenen, 2004, for an exception). The only major change to our stimulus was the size of each item (L and T) within each stimulus from 2° of visual angle in experiment 1 to 0.25° in experiment 2. It is currently unclear to us why this would have the effect of diminishing contextual cueing. Consequently, the size of items composing stimuli has become a lead for further empirical investigations on when and where people are likely to be contextually cued.

Acknowledgments

The research reported here was supported by a grant from the Air Force Office of Scientific Research (AFOSR #FA9550-06-1-0074) to Wayne Gray.

References

- Anderson, J. R. (1990). *The Adaptive Character of Thought*. Hillsdale, NJ: Erlbaum.
- Ballard, D. H., Hayhoe, M. M., Pook, P. K., & Rao, R. P. N. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences*, 20(4), 723-742.
- Chun, M. M., & Jiang, Y. (1998). Contextual Cueing: Implicit Learning and Memory of Visual Context Guides Spatial Attention. *Cognitive Psychology*, 36, 28-71.
- Findlay, J. M., & Gilchrist, I. D. (2003). *Active Vision: The Psychology of Looking and Seeing* (Vol. 37). Oxford: Oxford University Press.
- Franconeri, S. L., Simons, D. J., & Junge, J. A. (2004). Searching for stimulus-driven shifts of attention. *Psychonomic Bulletin & Review*, 11(5), 876-881.
- Gray, W. D., Neth, H., & Schoelles, M. (in press). The functional task environment. In A. F. Kramer, A. Kirlik & D. Wiegman (Eds.), *Applied attention*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Gray, W. D., Sims, C. R., Fu, W.-t., & Schoelles, M. (2006). The soft constraints hypothesis: A rational analysis approach to resource allocation for interactive behavior. *Psychological Review*, 113(3), 461-482.
- Grosbras, M. H., Leonards, U., Lobel, E., Poline, J. B., LeBihan, D., & Berthoz, A. (2001). Human cortical networks for new and familiar sequences of saccades. *Cerebral Cortex*, 11(10), 936-945.
- Hayhoe, M. M., Shrivastava, A., Mruczek, R., & Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *Journal of Vision*, 3(1), 49-63.
- Jiang, Y., & Wagner, L. C. (2004). What is learned in spatial contextual cueing – configuration or individual location? *Perception & Psychophysics*, 66(3), 454-463.
- Josephson, S., & Holmes, M. (2002). Attention to repeated images on the world-wide-web: Another look at scanpath theory. *Behavior Research Methods, Instruments, & Computers*, 24(4), 539-549.
- Laeng, B., & Teodorescu, D. S. (2002). Eye scanpaths during visual imagery reenact those of perception of the same visual scene. *Cognitive Science*, 26(2), 207-231.
- Lleras, A., & Von Muhlenen, A. (2004). Spatial context and top-down strategies in visual search. *Spatial Vision*, 17(4-5), 465-482.
- Myers, C. W., & Gray, W. D. (submitted). Regulating visual search: Optimizing initial saccades to the cost-structure of the visual task environment.
- Myers, C. W., & Schoelles, M. (2005). ProtoMatch: A tool for analyzing high-density, sequential eye gaze and cursor protocols. *Behavior Research Methods*, 37(2), 256-270.
- Noton, D., & Stark, L. W. (1971). Scanpaths in Eye Movements during Pattern Perception. *Science*, 171(3968), 308-311.
- Peterson, M. S., & Kramer, A. F. (2001). Contextual cueing reduces interference from task-irrelevant onset distractors. *Visual Cognition*, 8(6), 843-859.
- Song, J.-H., & Jiang, Y. (2005). Connecting the past with the present: How do humans match an incoming visual display with visual memory? *Journal of Vision*, 5, 322-330.
- Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review*, 11(1), 65-70.
- Zangemeister, W. H., Sherman, K., & Stark, L. (1995). Evidence For A Global Scanpath Strategy In Viewing Abstract Compared With Realistic Images. *Neuropsychologia*, 33(8), 1009-1025.