Anticipatory anxiety hinders detection of a second target in dual-target search

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Professional visual searches (e.g., baggage screening, military searches, radiological examinations) are often conducted in high-pressure environments and entail multiple visual targets. Yet, laboratory studies of visual search tend to be conducted in emotionally-neutral settings with only one possible target per display. The current experiment looked to better emulate high-pressure search conditions by presenting searchers with arrays that could contain 0-2 targets while inducing anticipatory anxiety via a threat of shock paradigm. Under conditions of anticipatory anxiety, dual-target performance was negatively impacted, but single-target performance and time-on-task were unaffected, suggesting that multiple-target searches may be a more sensitive instrument to measure the impact of environmental factors on visual cognition than single-target searches. Further, this effect was modulated by individual differences in state anxiety levels of participants prior to the experiment. These results have implications for both the laboratory study of visual search and the management and assessment of professional searchers.

Visual searches are conducted both in everyday activities such as finding a friend in a crowd, and in professional contexts such as in baggage screening, military searches, and radiological examinations. While some searches focus on the detection of single targets (e.g., finding a package of berries in a refrigerator), searches can also have multiple targets (e.g., checking whether one or more berries has become moldy). Multiple-target searches are common in professional settings, and, disconcertingly, they can be highly error prone (see Berbaum, Franklin, Caldwell, & Schartz, 2010 for a recent review). Given the significance of many professional searches, it is critical to determine what factors affect multiple-target search accuracy.

Single-target visual search has been studied extensively (Nakayama & Martini, 2010; Palmer, Verghese, & Pavel, 2000; Wolfe, 1994, 1998), yet relatively less psychological research has examined multiple-target search accuracy. Some important insight has come from the study of multiple-*category* searches (e.g., Godwin et al., 2010; Menneer, Barrett, Phillips, Donnelly, & Cave, 2007). In such searches, for example, a participant may look for guns and bombs in a baggage screening X-ray image, however no more than one target is ever present in a search display (i.e., a bomb *or* a gun, not a bomb *and* a gun). These studies reveal accuracy costs for looking for multiple categories of targets, but do not inform multiple-target search. Other studies have investigated visual search using multiple-target displays, but with a fixed number of targets or with the time to find all targets as the measure of interest (e.g., Chan & Courtney, 1995; Drury & Hong, 2000; Holmes, Peper, Olsho, & Raney, 1978; Horowitz & Wolfe, 2001; Neisser, 1974), which limits insight into multiple-target search accuracy.

Radiological research has explored a variety of factors impacting multiple-target search accuracy (e.g., Berbaum, Franklin, Dorfman, Caldwell, & Lu, 2005; Berbaum et al., 2001), and one key finding is that an abnormality is more likely to be missed when it is accompanied by an additional abnormality than when it is the only target present. This phenomenon, termed 'Satisfaction of Search' (SOS), has been demonstrated in a variety of medical image types and abnormalities (e.g., Ashman, Yu, & Wolfman, 2000; Berbaum et al., 2007, 1994; Franken et al., 1994; Samuel, Kundel, Nodine, & Toto, 1995). However, there is no consensus on the underlying causes. The original theory suggested that searchers discontinue their search after finding a target (Tuddenham, 1962), yet this has not seen full support (e.g., Berbaum et al., 2010; Fleck, Samei, & Mitroff, 2010). Another suggestion is that of a "perceptual set"—once a searcher finds a target of type A, they are set to look for more targets of type A and are less likely to notice targets of type B (Berbaum et al., 2010). Recent psychological evidence supports this theory, but shows that it cannot be the entire story (Fleck et al., 2010).

Cognitive psychology research has begun to explore SOS in non-radiological contexts (Clark, Fleck, & Mitroff, 2010; Fleck et al., 2010; Schneider & Shiffrin, 1977; Wolfe, Horowitz, & Kenner, 2005), and the goal of the current project is to use a controlled experimental design to explore the potential influence of anxiety on multiple-target search accuracy. Although real-world visual searches often have multiple potential targets and take place in highly stressful situations, no studies have yet investigated the role of situational anxiety on multi-target visual search accuracy.

Anticipating a negative event can often induce a state of anxiety, which has been shown to affect attention (e.g., Weltman, Smith, & Egstrom, 1971) and target perception (e.g., Tyler & Tucker, 1982) and, thus, might impair visual search. One reliable method used to induce anticipatory anxiety in a laboratory setting is to inform participants that they may receive an unpredictable aversive electrical stimulation. Such "threat of shock" paradigms generate increased autonomic arousal, as indexed through an increase in tonic sweat gland activity (skin conductance level, SCL), throughout the anticipatory period (Rhudy & Meagher, 2000). Using the threat of shock paradigm and SCL measurements, we explored how anticipatory anxiety affects multiple-target visual search performance.

Methods

Participants

Twelve individuals (5 females; 19–28 years-old, M=22.8) from the Duke University community volunteered for $10. The study was approved for use in human participants by the Duke Medical Center Institutional Review Board.

Stimuli & Apparatus

Stimuli were pairs of slightly offset perpendicular lines with a stroke width of 0.3° of visual angle and 1.3° x 1.3° extent, with viewing distance of approximately 24in. Targets were perfect 'T' shapes and appeared in one of two salience levels (high-salience: 57–65% black; low-salience: 22–45% black). On each trial there were 0–2 targets, resulting in four trial types: no-target (20%), single high-salience (48%), single low-salience (16%), and dual-target (both a high-salience and a low-salience target present; 16%). Trial type was equally distributed across conditions (see below) and the order was randomized over the experiment. Trial type proportions were chosen to not produce SOS errors under normal circumstances (i.e., without threat of shock; Fleck et al., 2010, Experiment 5).

Distractors were non-centered 'L' shapes ranging from 22–65% black (Figure 1). Each trial contained 25 total items arranged within an invisible 8x7 grid, with each item slightly jittered spatially. Each item appeared in one of four possible rotations, and all were on a background of grayscale "clouds" (4–37% black).

Shocks were delivered to the right wrist using STM-100 and STM-200 modules connected to a BIOPAC MP-150 system (BIOPAC systems, Goleta, CA). The shock was calibrated for each participant to a level deemed "highly annoying, but not painful" using an ascending staircase procedure (Dunsmoor, Mitroff, & LaBar, 2009). Skin conductance level (SCL) was assessed with the BIOPAC system using Ag/AgCl electrodes placed on the middle phalanx of the second and third digits of the left hand. SCL was analyzed using BIOPAC AcqKnowledge software. SCLs were scored as the mean response over whole trials and averaged across trials for each participant then log-transformed to attain normal distributions. One participant was not included in the SCL analysis due to lack of measurable electrodermal activity.

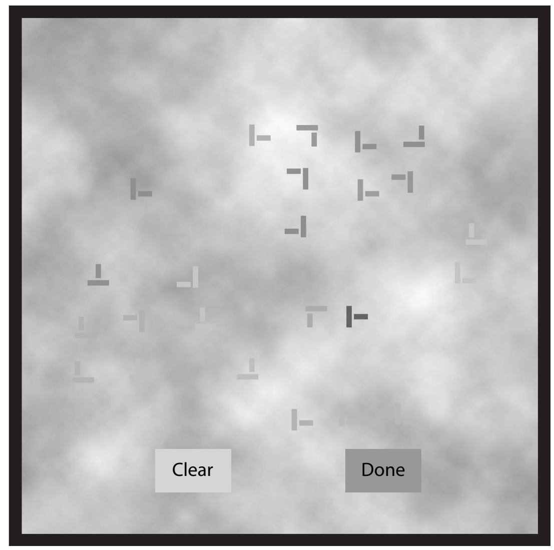

Figure 1. Sample search display. Each trial contained 0, 1, or 2 T-shaped targets among the pseudo-L-shaped distractors. The border's color (blue or green) signaled the block condition (shock or control) and was present throughout each block.

Procedure & Design

Participants' state and trait anxiety were measured immediately prior to the experiment with the State-Trait Anxiety Inventory (Spielberger, 1983).

During the experimental task, participants clicked on every target they found using a computer mouse and then clicked a blue button labeled 'DONE' when they had completed their search. The 'DONE' button appeared 3s after the trial began to ensure that participants engaged in the task without speeding through (Fleck et al., 2010). Participants could click a yellow 'CLEAR' button to reset their clicks. Trials had a time limit of 30s (no participants ever exceeded the time limit). Participants were told each trial contained 0–2 targets and asked to respond "as quickly and accurately as possible."

Two conditions were presented in 28 blocks of 10 trials each in a predefined pseudorandom order. The *threat of shock condition* was designed to induce anticipatory anxiety as participants were informed that during these blocks they could randomly receive a wrist shock that was not related to performance. Of the 14 possible shock blocks, shocks were administered in four, and those blocks were removed from all analyses. The *control condition* included anticipation of a potential stimulus, but without inducing anxiety. In four control blocks participants heard a 100 ms, 1000 Hz innocuous tone, unrelated to their performance, and those blocks were removed from all analyses. The first two experimental blocks were always a threat of shock block that delivered a shock and a control block that delivered a tone (order counterbalanced across participants). When a shock or tone was administered, it occurred randomly 1–15s after the start of a random trial in the block. If the trial ended before administration, it occurred the next trial.

Each block began with an instruction screen that informed participants of which type of stimulus to anticipate (i.e., shock or tone). Throughout the block there was a blue or green border around the screen, which served as a constant reminder of the block condition. The color/condition association was counterbalanced across participants.

The experiment began with a 10-trial practice block that had a pink border and was not analyzed. Unlike the experimental blocks, no shocks or tones were threatened and feedback was given after each trial.

Results

Group Analysis

SCLs were greater in the threat of shock condition than in the control condition (paired-samples $t(10)=3.59$, $p<0.005$), confirming that the threat of shock condition successfully enhanced autonomic arousal.

The primary measure was detection accuracy for low-salience targets. SOS was operationalized as superior low-salience target detection in single-target trials compared to dual-target trials. We calculated single-target accuracy by dividing the number of hits on single-target low-salience trials by the total number of such trials. We calculated dual-target accuracy by dividing the number of dual-target trials in which both targets were detected by the sum of the number of these trials and the number of dual-target trials in which only the high-salience target was detected (i.e., the low-salience target was missed), giving a conservative measure of SOS.

A 2x2 repeated-measures ANOVA was performed on detection accuracy for low-salience targets with condition (threat of shock vs. control) and number of targets (single vs. dual) as factors. A lack of a significant effect of condition ($F(1,11)=0.02$, $p=0.873$) indicates that there was not an overall worsening of performance due to threat of shock, and a lack of a significant main effect of number of targets ($F(1,11)=1.31$, $p=0.277$) indicates that dual-target performance was not worse overall. Importantly, the interaction between the factors was significant ($F(1,11)=8.52$, $p=0.014$), indicating that performance on dual-target trials was worse than on single-target trials (SOS), but *only* in the threat of shock condition (Figure 2). This was borne out in low-salience single-target vs. dual-target performance comparisons for each condition with a significant difference under threat of shock (paired $t(11)=2.98$, $p=0.015$) but not in the control condition (paired $t(11)=0.61$, $p=0.554$).

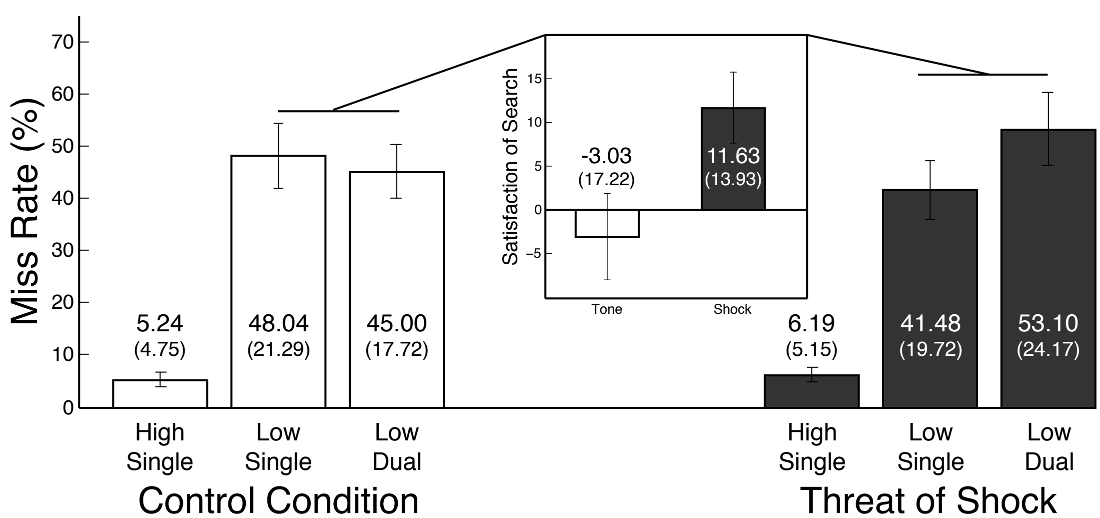

Figure 2. Threat of shock selectively leads to satisfaction of search, defined as better performance when a low-salience target is presented alone in a single-target trial than combined with a high-salience target in a dual-target trial. Column labels are means (and standard deviations). Error bars are standard error of the mean.

To look for other potential effects of anticipatory anxiety, we compared both high-salience single-target accuracy and dual-target detection accuracy between the threat of shock condition and the control condition. Performance was equally high in both (*ps*>0.6). Ruling out time-on-task effects (e.g., participants speeding up under anxiety), the time to click the 'DONE' button did not differ between conditions (threat of shock vs. control) for each trial type (high-salience single-target, low-salience single-target, dual-target, and no-target), and no comparison was significant (*ps*>0.1). Likewise, there were no differences between conditions on false alarm rates for any trial type (*ps*>0.1).

Individual Differences

Participants with higher state anxiety scores (range=20–40; M=29.75) showed less arousal sensitivity to the threat of shock manipulation. State anxiety and the SCL difference between the threat of shock and control conditions were negatively correlated (r(9)=-0.79, *p*<0.004; Figure 3), with participants with high state anxiety showing a smaller difference in SCLs between conditions. Importantly, the lack of differentiation in SCL in high anxious participants was driven by enhanced arousal during the control condition, suggesting that those with high anxiety were anxious during both conditions. Further, state anxiety was negatively correlated with the difference in SOS between the threat of shock condition and the control condition (r(10)=-0.57, *p*=0.052), indicating that individuals with heightened anxiety showed less SOS due to the threat of a shock. Examination of individual participants' performance indicates that those with high levels of state anxiety did not perform superiorly overall, but showed mild SOS for both conditions, leading to a reduced difference between conditions. Trait anxiety (range=22–43; M=31.25) effects did not approach significance.

Discussion

Anticipatory anxiety had a specific influence on visual search performance—anticipating a negative event increased SOS errors on dual-target trials while not affecting single-target performance or time-on-task. Compared to when participants were anticipating an innocuous tone, anticipating an aversive wrist shock generated greater autonomic responses and reduced the accuracy of detecting a second target after having found a first target.

This SOS effect was mediated by state anxiety: Because the threat of shock did not increase anxiety as much for individuals who were already anxious at the beginning of the study, it thus had a reduced impact on their accuracy difference between conditions. For persons with clinical anxiety disorders, threat of shock experiments have shown that arousal tends to be enhanced throughout the entire session and is not specific to conditions with threats of aversive events (e.g., Grillon, Morgan, Davis, & Southwick, 1998). This overall heightened arousal might reflect context conditioning—when the environment itself takes on emotional qualities due to the presentation of unpredictable shocks (Fanselow, 1980). Because professional visual searches often occur in high-stress environments, these findings have important practical implications for minimizing anxiety in the workplace.

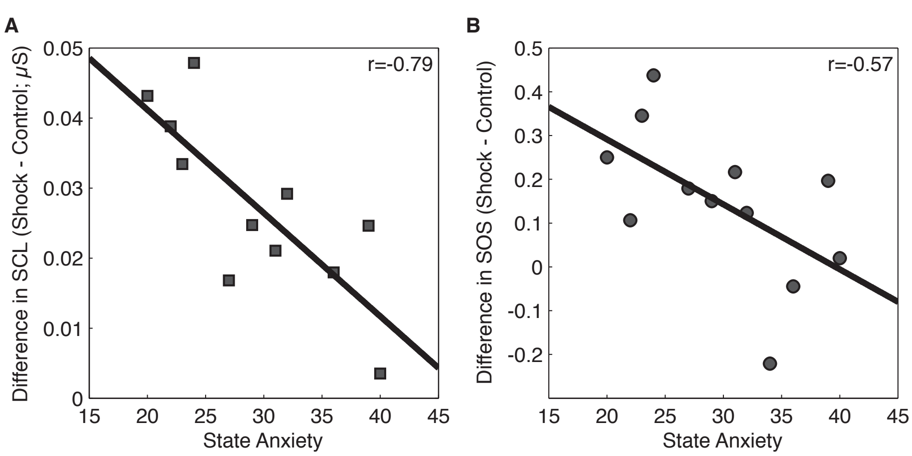

Figure 3. Correlations between state anxiety and the differential response between conditions. Individuals with higher state anxiety at the beginning of the experiment showed less of a difference between the threat of shock and control conditions—both (A) in skin conductance level (SCL) and (B) in satisfaction of search (SOS)—than individuals with lower state anxiety. μS = microsiemens.

The SOS effect seen here might be due to strategic changes or lower-level changes. The lack of a difference in time-on-task between conditions argues against a general 'speeding up' or 'premature search termination' strategy shift, in line with prior work (Berbaum et al., 1994). However, participants may make other strategy changes not discernable here, such as shifts in search pattern. The current data are compatible with a non-strategic attentional narrowing account (Berbaum et al., 2010)—when participants find a target of a particular type (e.g., a tumor) they may be more likely to find additional targets of that type at the expense of other types (e.g., fractures). Here, when a participant finds a high-salience target while experiencing anticipatory anxiety, they may develop heightened sensitivity to high-salience targets at the cost of low salience targets, in line with previous work linking anxious states with attentional narrowing (Easterbrook, 1959). Finally, another possible lower-level explanation for SOS is that high-salience targets that have already been found may serve as distractors when searching for further targets (Körner & Gilchrist, 2008), an effect which may be heightened under conditions of anticipatory anxiety.

These data have broad implications for occupational visual search execution and training. Many on-the-job assessments and training protocols for professional searchers use only single targets. Such assessments would likely fail to see effects of anticipatory anxiety, as only dual-target searches were affected here. Beyond assessing SOS, it is important to reduce such errors and, to that end, the current data suggest that the best performance arises when anticipatory anxiety in the search environment is minimized. In cases where anxiety cannot be easily reduced, such as soldiers on patrol, other measures will be needed to counteract SOS errors.

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References

Ashman, C. J., Yu, J. S., & Wolfman, D. (2000). Satisfaction of Search in Osteoradiology. *Am. J. Roentgenol.*, *175*(2), 541-544.

Berbaum, K. S., Franklin, E. A. J., Dorfman, D. D., Caldwell, R. T., & Lu, C. H. (2005). Can order of report prevent satisfaction of search in abdominal contrast studies? *Academic Radiology*, *12*(1), 74-84. doi:10.1016/j.acra.2004.11.007

Berbaum, K. S., Brandser, E. A., Franklin, E. A. J., Dorfman, D. D., Caldwell, R. T., & Krupinski, E. A. (2001). Gaze Dwell Times on Acute Trauma Injuries Missed Because of Satisfaction of Search. *Academic radiology*, *8*(4), 304–314.

Berbaum, K. S., El-Khoury, G. Y., Ohashi, K., Schartz, K. M., Caldwell, R. T., Madsen, M., & Franklin, E. A. J. (2007). Satisfaction of Search in Multitrauma Patients: Severity of Detected Fractures. *Academic radiology*, *14*(6), 711–722. doi:10.1016/j.acra.2007.02.016

Berbaum, K. S., El-Khoury, G. Y., Franken, E. A., Kuehn, D. M., Meis, D. M., Dorfman, D. D., Warnock, N. G., et al. (1994). Missed fractures resulting from satisfaction of search effect. *Emergency Radiology*, *1*(5), 242-249. doi:10.1007/BF02614935

Berbaum, K. S., Franklin, E. A. J., Caldwell, R. T., & Schartz, K. M. (2010). Satisfaction of Search in Traditional Radiographic Imaging. In E. Samei & E. Krupinski (Eds.), *The Handbook of Medical Image Perception and Techniques* (pp. 107-138). Cambridge University Press.

Chan, H. S., & Courtney, A. J. (1995). Visual performance on detection tasks with two targets. *International Journal of Human Factors in Manufacturing*, *5*(4), 417–428.

Clark, K., Fleck, M. S., & Mitroff, S. R. (2010, May). *Reducing satisfaction of search errors in visual search*. Poster presented at the Vision Sciences Society, Naples, FL. Retrieved from http://www.journalofvision.org/content/10/7/1301.abstract?sid=6457a377-8bb6-45b2-8253-bc0fcebc75e6

Drury, C. G., & Hong, S. K. (2000). Generalizing from single target search to multiple target search. *Theoretical Issues in Ergonomics Science*, *1*(4), 303–314.

Dunsmoor, J. E., Mitroff, S. R., & LaBar, K. S. (2009). Generalization of conditioned fear along a dimension of increasing fear intensity. *Learning & Memory*, *16*(7), 460-469. doi:10.1101/lm.1431609

Easterbrook, J. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, *66*(3), 183-201. doi:10.1037/h0047707

Fanselow, M. S. (1980). Conditional and unconditional components of post-shock freezing. *Integrative Psychological and Behavioral Science*, *15*(4), 177-182. doi:10.1007/BF03001163

Fleck, M. S., Samei, E., & Mitroff, S. R. (2010). Generalized 'satisfaction of search': Adverse influences on dual-target search accuracy. *Journal of Experimental Psychology: Applied*, *16*(1), 60-71. doi:10.1037/a0018629

Franken, E. A., Berbaum, K. S., Lu, C. H., Kannam, S., Dorfman, D. D., Warnock, N. G., Simonson, T. M., et al. (1994). Satisfaction of search in the detection of plain-film abnormalities in abdominal contrast studies. *Investigative Radiology*, *29*(4), 403-409.

Godwin, H. J., Menneer, T., Cave, K. R., Helman, S., Way, R. L., & Donnelly, N. (2010). The impact of Relative Prevalence on dual-target search for threat items from airport X-ray screening. *Acta psychologica*, *134*, 79-84. doi:10.1016/j.actpsy.2009.12.009

Grillon, C., Morgan, C. A., Davis, M., & Southwick, S. M. (1998). Effect of Darkness on Acoustic Startle in Vietnam Veterans With PTSD. *Am J Psychiatry*, *155*(6), 812-817.

Holmes, D. L., Peper, R., Olsho, L. W., & Raney, D. E. (1978). Searching for multiple targets simultaneously: Is it really possible? *Perceptual and Motor Skills*, *46*, 227-234.

Horowitz, T. S., & Wolfe, J. M. (2001). Search for multiple targets: Remember the targets, forget the search. *Perception & Psychophysics*, *63*(2), 272.

Körner, C., & Gilchrist, I. D. (2008). Memory processes in multiple-target visual search. *Psychological Research*, *72*(1), 99-105. doi:10.1007/s00426-006-0075-1

Menneer, T., Barrett, D. J. K., Phillips, L., Donnelly, N., & Cave, K. R. (2007). Costs in searching for two targets: dividing search across target types could improve airport security screening. *Applied Cognitive Psychology*, *21*(7), 915-932. doi:10.1002/acp.1305

Nakayama, K., & Martini, P. (2010). Situating visual search. *Vision Research*. doi:10.1016/j.visres.2010.09.003

Neisser, U. (1974). Practiced card sorting for multiple targets. *Memory & Cognition*, *2*(4), 781-785.

Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. *Vision Research*, *40*(10), 1227–1268.

Rhudy, J. L., & Meagher, M. W. (2000). Fear and anxiety: divergent effects on human pain thresholds. *Pain*, *84*(1), 65–75.

Samuel, S., Kundel, H. L., Nodine, C. F., & Toto, L. C. (1995). Mechanism of satisfaction of search: eye position recordings in the reading of chest radiographs. *Radiology*, *194*(3), 895-902.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, *84*(1), 1-66. doi:10.1037/0033-295X.84.1.1

Spielberger, C. D. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Tuddenham, W. J. (1962). Visual search, image organization, and reader error in roentgen diagnosis. Studies of the psycho-physiology of roentgen image perception. *Radiology*, *78*, 694-704.

Tyler, S. K., & Tucker, D. M. (1982). Anxiety and perceptual structure: Individual differences in neuropsychological function. *Journal of Abnormal Psychology*, *91*(3), 210-220. doi:10.1037/0021-843X.91.3.210

Weltman, G., Smith, J. E., & Egstrom, G. H. (1971). Perceptual narrowing during simulated pressure-chamber exposure. *Human Factors*, *13*(2), 99-107.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review*, *1*(2), 202-238.

Wolfe, J. M. (1998). What Can 1 Million Trials Tell Us about Visual Search? *Psychological Science*, *9*(1), 33-39.

Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). Rare items often missed in visual searches. *Nature*, *435*(7041), 439-440. doi:10.1038/435439a