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Anticipatory Anxiety Hinders Detection of a Second Target in Dual-Target Search

Matthew S. Cain, Joseph E. Dunsmoor, Kevin S. LaBar, and Stephen R. Mitroff
Center for Cognitive Neuroscience, Department of Psychology and Neuroscience, Duke University

Abstract

Professional visual searches (e.g., baggage screenings, military searches, radiological examinations) are often conducted in high-pressure environments and require focus on multiple visual targets. Yet laboratory studies of visual search tend to be conducted in emotionally neutral settings with only one possible target per display. In the experiment reported here, we looked to better emulate high-pressure search conditions by presenting searchers with arrays that contained between zero and two targets while inducing anticipatory anxiety via a threat-of-shock paradigm. Under conditions of anticipatory anxiety, dual-target performance was negatively affected, but single-target performance and time on task were unaffected. These results suggest that multiple-target searches may be a more sensitive instrument to measure the effect of environmental factors on visual cognition than single-target searches are. Further, the effect of anticipatory anxiety 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.

Keywords

visual search, anxiety, individual differences

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Visual searches are conducted both in everyday activities, such as finding a friend in a crowd, and in professional contexts, such as in baggage screenings, military searches, and radiological examinations. Although some searches focus on the detection of single targets (e.g., finding a package of berries in a refrigerator), other searches have multiple targets (e.g., checking whether one or more berries in the package have become moldy). Multiple-target searches are common in professional settings, and, disconcertingly, searches for more than one target 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 (e.g., Nakayama & Martini, 2010; Palmer, Verghese, & Pavel, 2000; Wolfe, 1994), yet relatively little 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 that accuracy decreases when searchers look for multiple categories of targets, but these results do not necessarily apply to searches for multiple targets within a category. 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., Drury & Hong, 2000; Holmes, Peper, Olsho, & Raney, 1978; Horowitz & Wolfe, 2001; Neisser, 1974); neither arrangement provides direct insight into multiple-target search accuracy.

Radiological research has explored a variety of factors affecting 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., 1994; Franken et al., 1994; Samuel, Kundel, Nodine, & Toto, 1995).

Corresponding Author:
Matthew S. Cain, Center for Cognitive Neuroscience, B203 LSRC, Box 90999, Duke University, Durham, NC 27708
E-mail: matthew.s.cain@duke.edu

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However, there is no consensus on the underlying causes of SOS. The original theory suggested that searchers discontinue their search after finding a target (Tuddenham, 1962), yet this hypothesis has not seen full support (e.g., Berbaum et al., 2010; Fleck, Samei, & Mitroff, 2010). Another suggestion is that searchers develop a *perceptual set*—once searchers find 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).

Research in cognitive psychology has begun to explore SOS in nonradiological contexts (Clark, Fleck, & Mitroff, 2010; Fleck et al., 2010; Schneider & Shiffrin, 1977; Wolfe, Horowitz, & Kenner, 2005), and the goal of the project reported in this article was 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 the accuracy of multiple-target visual searches.

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, or SCL), throughout the anticipatory period (Rhudy & Meagher, 2000). Using the threat-of-shock paradigm and SCL measurements, we explored how anticipatory anxiety affected performance on multiple-target visual searches.

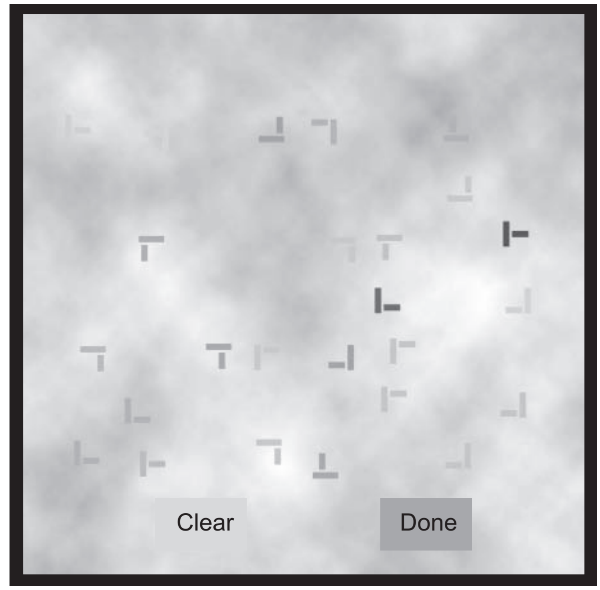

Fig. 1. Sample search display used in the experiment. Stimuli consisted of pairs of rectangles, with the members of each pair oriented perpendicularly to each other to form perfect T shapes (targets) or non-T shapes (distractors). Each trial contained no, one, or two targets among 23 to 25 distractors (a display with two targets and 23 distractors is shown here). Targets were made more or less salient by increasing or decreasing their black level. Stimuli were presented on a background of gray-scale "clouds." The color of the border around the display, shown here in black, changed between blue and green to signal the block condition (threat of shock or no threat, respectively). Participants clicked "Done" when they completed their search for targets, or "Clear" to reset their clicks.

Method

Participants

Twelve individuals (5 females, 7 males; age range = 19–28 years, M = 22.8 years) from the Duke University community volunteered to participate in return for $10. The study was approved by the Duke Medical Center Institutional Review Board.

Stimuli and apparatus

Stimuli were pairs of rectangles with a width of 0.3° of visual angle; each pair was contained within the bounds of an invisible 1.3° × 1.3° square (Fig. 1). The members of each pair were oriented perpendicularly to each other and slightly separated. Targets were perfect T shapes and appeared in one of two salience levels (high salience: 57%–65% black; low salience: 22%–45% black). Distractors were non-T shapes ranging from 22% to 65% black. Each trial contained 25 total items arranged within an invisible 8 × 7 grid, with each item slightly offset spatially from perfect grid alignment. Each item appeared in one of four possible rotations, and all were on a background of gray-scale "clouds" (4%–37% black).

Shocks were delivered to the right wrist using STM100 and STM200 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). 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.

Procedure and design

On each trial, there were between zero and two targets, resulting in four trial types: no target (20% of trials), single high-salience target (48% of trials), single low-salience target (16% of trials), and dual target (in which both a high-salience target and a low-salience target were present; 16% of trials). We chose these trial-type proportions because it has been shown

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that they do not produce SOS errors under normal circumstances (i.e., in which no threat of shock exists; Fleck et al., 2010, Experiment 5). Trial types were equally distributed across conditions, and the order of trial types was randomized over the experiment. Participants' state and trait anxiety were measured immediately prior to the experiment with the State-Trait Anxiety Inventory (Spielberger, 1983).

Participants viewed the stimuli at a distance of approximately 24 in. During each trial, 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 3 s after the trial began to ensure that participants engaged in the task without speeding through it (Fleck et al., 2010). Participants could click a yellow "Clear" button to reset their clicks. Trials had a time limit of 30 s (no participants exceeded the time limit). Participants were told each trial contained between zero and two targets and were 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: Participants were informed that during these blocks, they could randomly receive a wrist shock that was not related to performance. Of the 14 threat-of-shock blocks, shocks were administered in four, and those blocks were removed from all analyses. The control condition consisted of 14 blocks that included anticipation of a potential stimulus, but without inducing anxiety. In four control blocks, participants heard an innocuous 100 ms, 1000 Hz 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 was counterbalanced across participants). When a shock or tone was administered, it occurred randomly 1 s to 15 s after the start of a random trial in the block. If the trial ended before administration of the tone or shock, it occurred on 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, a blue or green border around the screen 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 in which the screen had a pink border. This block was not analyzed. Unlike in the experimental blocks, no shocks or tones were threatened, and feedback was given after each trial.

Results

Group analysis

SCLs were scored as the mean response over whole trials, averaged across trials for each participant, and then log transformed to attain normal distributions. One participant was not included in the SCL analysis because of lack of measurable electrodermal activity. SCLs were greater in the threat-of-shock condition than in the control condition, paired-samples $t(10) = 3.59$, $p < .005$, and this confirmed 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 relative 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 this number and the number of dual-target trials in which only the high-salience target was detected (i.e., the low-salience target was missed); this procedure gave a conservative measure of SOS.

A 2 × 2 repeated measures analysis of variance (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. The lack of a significant effect of condition, $F(1, 11) = 0.02$, $p = .873$, indicated that there was not an overall worsening of performance due to threat of shock, and the lack of a significant main effect of number of targets, $F(1, 11) = 1.31$, $p = .277$, indicated that dual-target performance was not worse overall. It is important to note that the interaction between the factors was significant, $F(1, 11) = 8.52$, $p = .014$, indicating that performance on dual-target trials was worse than on single-target trials (demonstrating SOS), but only in the threat-of-shock condition (Fig. 2). This was borne out in low-salience single-target vs. dual-target performance comparisons for each condition, which revealed a significant difference between the two trial types in the threat-of-shock condition, paired $t(11) = 2.98$, $p = .015$, but not in the control condition, paired $t(11) = 0.61$, $p = .554$.

To look for other potential effects of anticipatory anxiety, we compared both high-salience single-target detection accuracy with dual-target detection accuracy in both the threat-of-shock condition and the control condition. Performance was equally high in both conditions (ps > .6). Ruling out time-on-task effects (e.g., participants speeding up under anxiety), we found that the time to click the "Done" button did not differ between the two conditions for each trial type (high-salience single target, low-salience single target, dual target, and no target), and no comparison was significant (ps > .1). Likewise, there were no differences between conditions on false alarm rates for any trial type (ps > .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 than did participants with lower state anxiety scores. State anxiety and the SCL difference between the threat-of-shock and control conditions were negatively correlated, $r(9) = -.79$, $p < .004$ (Fig. 3a), with participants with

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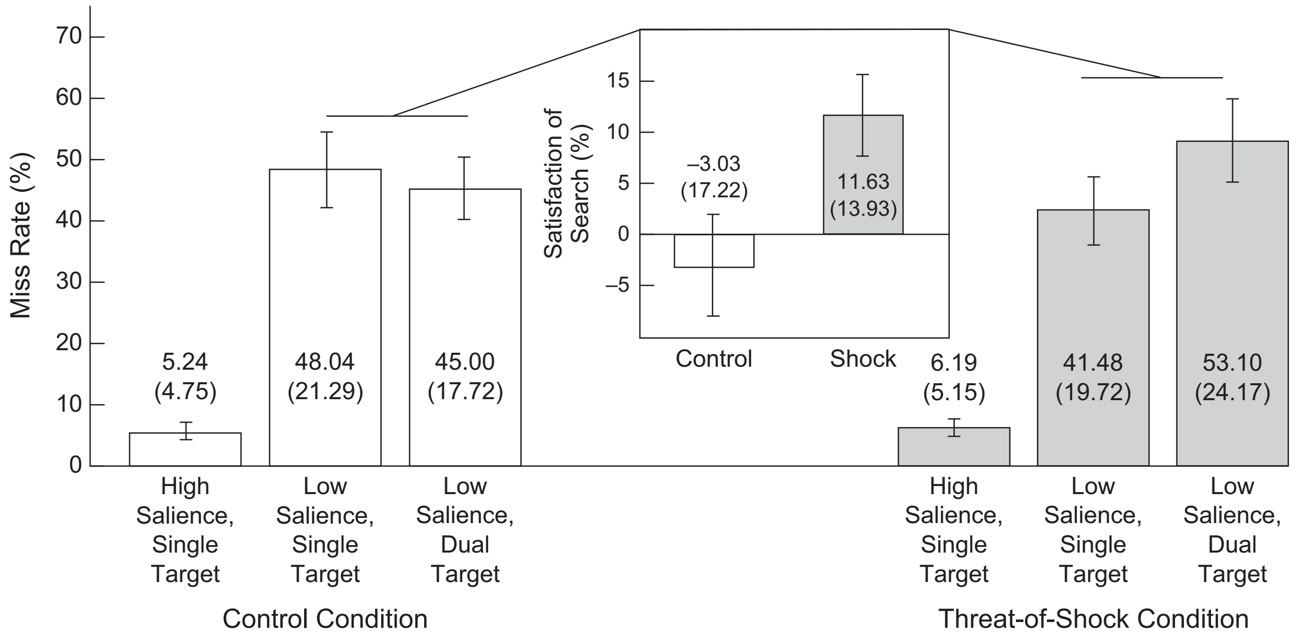

Fig. 2. Results from the experiment. The mean percentage of misses is shown as a function of trial type separately for the threat-of-shock and control conditions. Trials consisted of displays containing single high-salience targets, single low-salience targets, or dual targets (one of high salience and one of low salience). For dual-target trials, the figure presents the miss rate for low-salience targets on trials in which the high-salience target was detected. The satisfaction-of-search percentage (inset graph) was calculated for each condition by subtracting the mean miss rate for dual-target searches in which the high-salience target was detected (i.e., the miss rate for low-salience targets) from the mean miss rate for low-salience single-target searches. The numbers above and inside the bars are means, with standard deviations given in parentheses. Error bars show standard errors of the mean.

high state anxiety showing a smaller difference in SCLs between conditions. It is important to note that the lack of differentiation in SCL in highly anxious participants was driven by enhanced arousal during the control condition, a finding suggesting that participants 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, $r(10) = -.57$, $p = .052$ (Fig. 3b); this result indicates that individuals with heightened anxiety showed less SOS under threat of a shock. Examination of individual participants' performance indicates that those with high levels of state anxiety did not show superior performance overall, but showed mild SOS for both conditions, leading to a reduced difference between conditions. The correlations with trait-anxiety scores (range = 22–43; $M = 31.25$) 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 but did not affect performance on single-target trials or time on task. Compared with anticipation of 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 effect on the difference in their accuracy 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 because of 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.

The SOS effect seen in this experiment 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 strategy shift leading to speeding up or premature search termination (an interpretation in line with findings of 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 nonstrategic 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). In the

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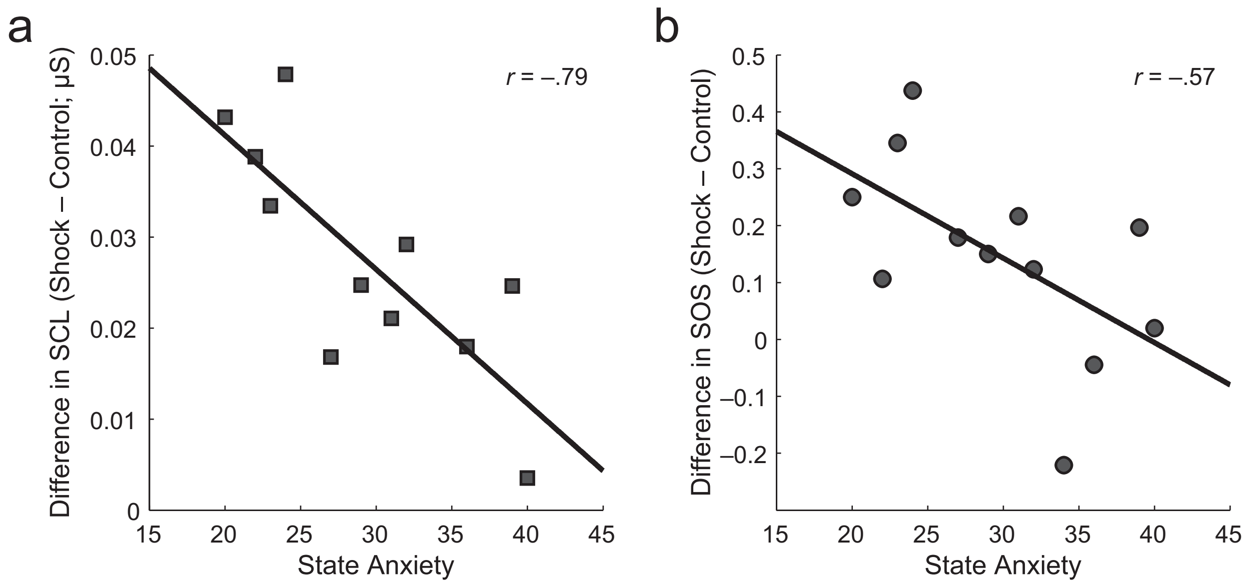

Fig. 3. Scatter plots (with best-fitting regression lines) showing the differences in (a) skin conductance level (SCL) and (b) satisfaction of search (SOS) between the two conditions (threat of shock vs. control) as a function of state anxiety.

study reported here, when a participant found a high-salience target while experiencing anticipatory anxiety, he or she may have developed heightened sensitivity to high-salience targets at the cost of low-salience targets (an effect in line with the findings of 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 in our experiment. 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 in which anxiety cannot be easily reduced, such as when soldiers are on patrol, other measures will be needed to counteract SOS errors.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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