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14. ABSTRACT
The primary objective of this ARO-funded project was to explore a particularly troublesome issue for visual search—multiple-target visual searches (where more than one target can possibly be present at the same time). Multiple-target searches are common in many settings (e.g., baggage screening, military searches), and they are especially error prone. To better understand the nature of multiple-target search to inform both academic theory and real-world performance, we enacting a multifaceted experimental approach. First, we administered laboratory-based experiments in conjunction with a large set of individual differences measures. The experiments were

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Report Title

Final Report: Identifying and Understanding Superior Multiple-Target Visual Search Abilities

ABSTRACT

The primary objective of this ARO-funded project was to explore a particularly troublesome issue for visual search—multiple-target visual searches (where more than one target can possibly be present at the same time). Multiple-target searches are common in many settings (e.g., baggage screening, military searches), and they are especially error prone. To better understand the nature of multiple-target search to inform both academic theory and real-world performance, we enacting a multifaceted experimental approach. First, we administered laboratory-based experiments in conjunction with a large set of individual differences measures. The experiments were designed to reveal the underlying mechanisms that lead to multiple-target search errors and to reveal why some individuals are more capable searchers than others. Second, we made use of mobile app technology to examine the nature of multiple-target search from a "big data" perspective—with billions of trials, we had the power to ask critically important nuanced questions that cannot be addressed in a laboratory setting. We made headway on both fronts, and details are provided in this report. Note that this award was ended early as the PI moved changed universities. A new award has begun that continues the efforts and more.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/05/2015	1.00	Adam T Biggs, Stephen H Adamo, Stephen R Mitroff. Mo' money, mo' problems: Monetary motivation can exacerbate the attentional blink, Perception, (02 2015): 0. doi: 10.1068/p7916
08/05/2015	2.00	Emma Wu Dowd, Anastasia Kiyonaga, Tobias Egner, Stephen R. Mitroff. Attentional guidance by working memory differs by paradigm: An individual-differences approach, Attention, Perception, & Psychophysics, (03 2015): 0. doi: 10.3758/s13414-015-0847-z
08/05/2015	3.00	Adam T. Biggs, Stephen H. Adamo, Emma Wu Dowd, Stephen R. Mitroff. Examining perceptual and conceptual set biases in multiple-target visual search, Attention, Perception, & Psychophysics, (02 2015): 0. doi: 10.3758/s13414-014-0822-0
08/05/2015	4.00	Stephen R. Mitroff, Adam T. Biggs, Stephen H. Adamo, Emma Wu Dowd, Jonathan Winkle, Kait Clark. What can 1 billion trials tell us about visual search?, Journal of Experimental Psychology: Human Perception and Performance, (01 2015): 0. doi: 10.1037/xhp0000012
08/05/2015	5.00	Adam T. Biggs, Stephen R. Mitroff. Improving the Efficacy of Security Screening Tasks: A Review of Visual Search Challenges and Ways to Mitigate Their Adverse Effects, Applied Cognitive Psychology, (01 2015): 0. doi: 10.1002/acp.3083
08/05/2015	6.00	Adam T. Biggs, Stephen R. Mitroff. Differences in multiple-target visual search performance between non-professional and professional searchers due to decision-making criteria, British Journal of Psychology, (09 2014): 0. doi: 10.1111/bjop.12096
08/05/2015	7.00	Adam T. Biggs, Stephen H. Adamo, Stephen R. Mitroff. Rare, but obviously there: Effects of target frequency and salience on visual search accuracy, Acta Psychologica, (10 2014): 0. doi: 10.1016/j.actpsy.2014.08.005
TOTAL:	**7**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Ericson, J. M., Mitroff, S. R., & Sharpe, B. (2016, September). Long-term visual search: Using mobile app "big data" to reveal key aspects of experience in visual search. Paper presented at the annual meeting of the Human Factors & Ergonomic Society, Washington D.C.

Mitroff, S. R. (2016, May). Improving performance of human operators. Paper presented at 14th annual Awareness and Locatization of Explosives-related Threats Workshop. Boston, MA.

Mitroff, S. R., Winkle, J., Ericson, J. M., & Gancayco, C. A. (2015, November). The long and short of visual search: Examining both long- and short-term influences on search performance. Paper presented at the annual meeting of the Psychonomic Society, Chicago, IL.

Ericson, J. M., Winkle, J., & Mitroff, S. R., (2015, November). Moving at the speed of search: Long-term visual search and the influence of lapses in time between search activity. Poster presented at the annual meeting of the Psychonomic Society, Chicago, IL.

Adamo, S. H., Cain, M. S., & Mitroff, S. R. (2015, November). Satisfaction at last: Evidence for the "satisfaction" hypothesis for multiple-target search errors. Paper presented at the annual Object Perception, Attention, and Memory meeting, Chicago, IL

Mitroff, S. R., Biggs, A. T., Ericson, J. M., Winkle, J., Gancayco, C. A., Adamo, S. H., & Wu Dowd, E. (2015, September). Using mobile technology (and big data) to understand medical errors. Paper presented at the Diagnostic Error in Medicine 8th International Conference, Washington, D.C.

Mitroff, S. R., Biggs, A. T., Ericson, J. M., Winkle, J., Adamo, S. H., & Wu Dowd, E. (2015, June). Using mobile technology (and big data) to inform radiological research. Paper presented at the annual meeting of the Medical Imaging Perception Society, Ghent, Belgium.

Ericson, J. M., Biggs, A. T., Winkle, J. A., Gancayco, C. A., & Mitroff, S. R. (2015, May). Long-term visual search: Examining trial-by-trial learning over extended visual search experiences. Talk presented at the annual meeting of the Vision Sciences Society, St. Pete Beach, FL.

Adamo, S. H., Cain, M. S., & Mitroff, S. R. (2015, May). An individual differences approach to multiple-target search errors: Errors correlate with attentional deficits. Poster presented at the annual meeting of the Vision Sciences Society, St. Pete Beach, FL.

Winkle, J. A., Biggs, A. T., Ericson, J. M., & Mitroff, S. R. (2015, May). For better or worse: Prior trial accuracy affects current trial performance in visual search. Poster presented at the annual meeting of the Vision Sciences Society, St. Pete Beach, FL.

Mitroff, S. R., Biggs, A. T., Adamo, S. H., Dowd, E. W., Winkle, J. & Clark, K. (2014, November). What can 1,000,000,000 trials tell us about visual search? Paper presented at the annual meeting of the Psychonomic Society, Long Beach, CA.

Biggs, A. T., Adamo, S. H., Dowd, E. W., & Mitroff, S. R. (2014, November). Perceptual and conceptual set biases in multiple-target visual search. Poster presented at the annual meeting of the Psychonomic Society, Long Beach, CA.

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Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received	Book Chapter
09/22/2016 20.00	Kait Clark, Matthew Cain, Stephen Mitroff. Perception and human information processing in visual search, : Cambridge University Press, (2015)

TOTAL: **1**

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Stephen Adamo	0.00	
Jonathan Winkle	0.00	
Emma Wu Dowd	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Justin Ericson	0.95
FTE Equivalent:	**0.95**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Stephen Mitroff	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):.....	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:.....	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME	
Stephen Adamo	
Emma Wu Dowd	
Total Number:	**2**

Names of other research staff

NAME	PERCENT_SUPPORTED
Christina Gancayco	0.50
FTE Equivalent:	**0.50**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Any task in which a soldier is responsible for conducting visual searches that may contain more than one target (e.g., looking for contraband, vehicle inspections) is open to dangerously high miss rates. There are two important ways to counteract this problem: (1) understand the nature of multiple-target search errors such that standard operating procedures can be appropriately modified and (2) find the right people for the job. This project simultaneously addressed both of these solutions by combining controlled laboratory-based experiments, individual differences assessments, and the power of "big data" from mobile app technology.

To examine the nature of multiple-target search, we (1) administered laboratory-based tasks and assessed individual differences and (2) analyzed data from a mobile app. A continuation of this award (as a new ARO grant) is currently underway at George Washington University. The new award will continue efforts #1 and #2 as well as combine these two approaches into one protocol.

Below I highlight several of the accomplishments.

1. Contributing mechanism to multiple-target search errors—perceptual and conceptual set biases.
Biggs, A. T., Adamo, S. H., Dowd, E. W., & Mitroff, S. R. (2015). Examining perceptual and conceptual set biases in multiple-target visual search. Attention, Perception, & Psychophysics, 77, 844-855. DOI 10.3758/s13414-014-0822-0

One hypothetical cause of multiple-target search errors is that searchers become biased to detect additional targets that are similar to a found target, and therefore become less likely to find additional targets that are dissimilar to the first target. This particular hypothesis has received theoretical, but little empirical, support. In this project, we tested the bounds of this idea by utilizing "big data" obtained from the mobile application Airport Scanner. Multiple-target search errors were substantially reduced when the two targets were identical, suggesting that the first-found target did indeed create biases during subsequent search. Further analyses delineated the nature of the biases, revealing both a perceptual set bias (i.e., a bias to find additional targets with features similar to those of the first-found target) and a conceptual set bias (i.e., a bias to find additional targets with a conceptual relationship to the first-found target).
A potential underlying mechanism of the similarity bias is priming, either perceptual or conceptual. Perceptual priming effects, in which repeated stimuli are identified better, are typically explained by a sharpening of the stimulus representation upon repeated exposure (see Wiggs & Martin, 1998). Conceptual priming effects are based on the idea of spreading activation, in which the initial processing of a stimulus automatically spreads to semantically related stimuli (e.g., Collins & Loftus, 1975). In both cases, finding a first target may reduce the processing threshold for other, perceptually or conceptually related stimuli, thus improving the detection of a similar second target (e.g., Kristjánsson & Campana, 2010).
Another possible explanation for the similarity bias involves aspects of memory-guided attention (see Hutchinson & Turk-Browne, 2012). Several studies have shown that encoding and maintaining an item in working memory appears to bias attention toward memory-matching items in a search array (see Soto, Hodsoll, Rotshtein, & Humphreys, 2008, and Olivers, Peters, Houtkamp, & Roelfsema, 2011, for reviews; but see also Woodman & Luck, 2007), above and beyond the influence of priming (Dowd & Mitroff, 2013; Downing, 2000; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). In this study, participants actively processed and interacted with the first-found target, by explicitly tapping on the item. This conscious and explicit interaction with the first target (as opposed to the mere exposure that is typified by pure priming) may have encoded its perceptual and conceptual features into working memory (see Cain & Mitroff, 2013). Maintaining these features in working memory could have then biased attention toward other items in the same array that shared those perceptual and/or conceptual features.

2. Contributing mechanism to multiple-target search errors—Satisfaction account.
Adamo, S. H., Cain, M. S., & Mitroff, S. R. (under revision). Satisfaction at last: Evidence for the satisfaction account for multiple-target search errors.
To eradicate multiple-target visual search errors it is vital to understand their cause(s), and this study investigated a key proposed mechanism—searchers prematurely terminate their search after finding a first target (the "satisfaction" account). Despite being proposed over 50 years ago, there are no conclusive supporting data for this account. Here, an individual differences approach revealed that accuracy on a multiple-target search task related to how long participants searched after finding a first target. This relationship was highly significant, even when accounting for variation in participants' attentional vigilance. This study provides evidence for the previously elusive "satisfaction" account, and adds to the growing understanding that multiple-target visual search errors are a multifaceted problem.

3. Individual differences approach—multiple-target visual search between novice and expert searchers.
Biggs, A. T., & Mitroff, S. R. (2014). Differences in multiple-target visual search performance between non-professional and professional searchers due to decision-making criteria. British Journal of Psychology. doi: 10.1111/bjop.12096

Professional visual searches, such as those conducted by airport security personnel, often demand highly accurate performance. As many factors can hinder accuracy, it is critical to understand the potential influences. Here, we examined how explicit decision-making criteria might affect multiple-target search performance. Non-professional searchers (college

undergraduates) and professional searchers (airport security officers) classified trials as ‘safe’ or ‘dangerous’, in one of two conditions. Those in the ‘one = dangerous’ condition classified trials as dangerous if they found one or two targets, and those in the ‘one = safe’ condition only classified trials as dangerous if they found two targets. The data suggest an important role of context that may be mediated by experience; non-professional searchers were more likely to miss a second target in the one = dangerous condition (i.e., when finding a second found target did not change the classification), whereas professional searchers were more likely to miss a second in the one = safe condition.

The goal of the current manuscript was to investigate whether global decision-making criteria about a visual search task could influence search performance during the task. Previous evidence demonstrated that multiple-target visual search errors are affected by contextual conditions surrounding the search (Clark et al., 2013), which provided the opportunity here to examine differences in performance due to a specific contextual influence – manipulations of the searchers’ decision-making criteria. In this study, all participants were given the same primary task – find each and every target present – but the decision-making criterion about how to classify trials differed by condition. Those in the one = dangerous condition were instructed to label a trial as dangerous if they found one or two targets, and those in the one = safe condition were instructed to label a trial as dangerous only if they found two targets. These labels did not change the within-trial goals, but nevertheless changed performance between non-professional and professional searchers.

The findings suggest that the pattern of results depended upon whether the searchers had professional training or not. The non-professional searchers fit the hypothesized result pattern, demonstrating fewer second-target errors when finding a second target altered how a trial was classified. This fits with expectations that when additional data can alter a classification, participants will spend more time searching for that data to ensure accuracy. Professional searchers, however, showed the opposite pattern – increased second-target errors when a second target altered how a trial was classified. So, why would professional searchers react differently to the same decision-making criterion? It is possible that, upon deeming some of the contents to be safe (as a lone found target would be in the one = safe condition), they were likely to judge the rest of the display content in a similar fashion. Professional searchers could become more complacent in their subsequent search upon finding a ‘safe’ first target, which suggests that the mindset of a professional searcher might be more vulnerable to contextual conditions about the search than non-professional searchers. This interpretation is further supported by the evidence that professional searchers were less likely to commit SSM errors when a found target indicated danger – a scenario akin to finding explosives concealed in luggage.

4. Individual differences approach—Relationship between visual search and personality measures in professional searchers.
Biggs, A. T., Clark, K., & Mitroff, S. R. (submitted). Who should be searching? Differences in personality can affect visual search accuracy.

It is essential to identify all factors impacting visual search performance, especially for tasks where success is critically important. Prior work has shown a variety of influences on search, including “bottom-up” (i.e., physical stimulus attributes) and “top-down” factors (i.e., task-relevant or goal-driven aspects). Recent work has begun to focus on “observer-specific” factors, examining how searchers’ attributes might influence search performance. A logical extension of this work is to explore whether some individuals might simply be better suited to conduct some visual searches than other individuals. The current study examined whether certain personality characteristics might relate to visual search performance in a large sample of professional searchers employed by the U.S. Transportation Security Administration. Of the “big five” personality traits (neuroticism, extroversion, openness, agreeableness, and conscientiousness), only conscientiousness was significantly correlated with visual search accuracy. Both early-career and experienced professional searchers demonstrated a significant relationship between conscientiousness scores and accuracy on a simple visual search task. These findings validate the notion that searchers’ attributes can impact their visual search performance and suggest that personality assessments might prove useful for hiring and selection decisions regarding professional tasks that incorporate visual search.

5. Individual Differences—Multiple-target search and attention.
Adamo, S. H., Cain, M. S., & Mitroff, S. R. (in press). An individual differences approach to multiple-target visual search errors: How search errors relate to different characteristics of attention. Vision Research.

Increasingly, evidence supports a resource depletion account of multiple-target visual search errors—a first target consumes attentional resources leaving fewer available to process a second target. However, “attention” is broadly defined and is composed of many different characteristics, leaving considerable uncertainty about how attention affects second-target detection. The goal of this study was to identify which attentional characteristics (i.e., selection, limited capacity, modulation, and vigilance) related to second-target misses. The current study compared second-target misses to two other attention-demanding tasks, attentional blink and vigilance, which have established measures that were used to operationally define each of the four attentional characteristics. Second-target misses in a multiple-target search were significantly correlated with (1) a measure of how long it took second target accuracy in an attentional blink task to recover from the blink (i.e., modulation), and (2) target sensitivity (d') in the vigilance task (i.e., vigilance). Participants who took longer to recover from an attentional blink and who were less vigilant had more second-target misses in a multiple-target search task. Taken together, these results support a resource depletion account of multiple-target search errors and highlight that worse modulation and poor vigilance reflect a deficit in attentional resources that can account for multiple-target search errors.

6. Reviews and overviews—Using Big Data to inform visual search and concerns for professional searchers
Mitroff, S. R., Biggs, A. T., Adamo, S. H., Dowd, E. W., Winkle, J., & Clark, K. (2014). What can 1 billion trials tell us about visual search? Journal of Experimental Psychology: Human Perception & Performance. DOI: 10.1037/xhp0000012

Mitroff, S. R., Biggs, A. T., & Cain, M. S. (2015). Multiple-target visual search errors: Overview and implications for airport security. Policy Insights from the Behavioral and Brain Sciences, 2(1), 121-128. DOI: 10.1177/2372732215601111

Biggs, A. T., & Mitroff, S. R. (2014). Improving the efficacy of security screening tasks: A review of visual search challenges and ways to mitigate their adverse effects. Applied Cognitive Psychology, 29(1), 142-148. DOI: 10.1002/acp.3083

During the course of this award, we wrote 3 review/overview articles related to this ARO-funded project. They offer high-level treatments of multiple-target visual search and the state of the research. They also have a strong focus on applied aspects and on the use of big data.
In the Mitroff et al. (JEP:HPP, 2014) publication, we discussed 2 examples of how data from the mobile game Airport Scanner (Kedlin Co., http://www.airportscannergame.com) can be used to address questions about the nature of visual search that pose intractable problems for laboratory-based research. Airport Scanner is a successful mobile game with millions of unique users and billions of individual trials, which allows for examining nuanced visual search questions. The goals of the current Observation Report were to highlight the growing opportunity that mobile technology affords psychological research and to provide an example roadmap of how to successfully collect usable data. This short report article highlighted the power of our ARO-funded project—we can leverage the big data from Airport Scanner to answer previously unreachable questions. We described the pros and cons of using mobile app data and then provided a few examples.

7. Contributing mechanism to multiple-target search errors—clutter.
Adamo, S. H., Cain, M. S., & Mitroff, S. R. (2015). Targets need their own space: Effects of clutter on multiple-target visual search. Perception, 44(10), 1203-1214. DOI: 10.1177/0301006615594921

Accuracy is critical for visual search, however there are often potentially negative influences that can affect performance; for example, the displays can be cluttered and can contain multiple targets. Previous research has demonstrated that clutter can hurt search performance and a second target is less likely to be detected in a multiple-target search array after a first target has already been found, which raises a concern—how does clutter affect multiple-target search performance? The current study explored clutter in a multiple-target search paradigm where there could be 1 or 2 targets present on a given trial, and targets appeared in varying levels of clutter. There was a significant interaction between clutter and target number: increasing levels of clutter did not affect single-target detection, but did significantly reduce detection of a second target in a dual-target trial. Multiple-target search accuracy is known to be sensitive to contextual influences, and the current results reveal a specific effect wherein clutter disproportionally affected multiple-target search accuracy. These results suggest that the detection and processing of a first target might enhance the masking effects of clutter around a second target.

8. Mechanisms of performance—Undertanding learning in visual search
Ericson, J. M., Kravitz, D., & Mitroff, S. R. (submitted). Visual Search: You are who you are (+ a learning curve).

Mitroff, S. R., Winkle, J., Ericson, J. M., & Gancayco, C. A. (2015, November). The long and short of visual search: Examining both long- and short-term influences on search performance. Paper to be presented at the annual meeting of the Psychonomic Society, Chicago, IL.

Ericson, J. M., Winkle, J., & Mitroff, S. R., (2015, November). Moving at the speed of search: Long-term visual search and the influence of lapses in time between search activity. Poster to be presented at the annual meeting of the Psychonomic Society, Chicago, IL.

Ericson, J. M., Biggs, A. T., Winkle, J. A., Gancayco, C. A., & Mitroff, S. R. (2015, May). Long-term visual search: Examining trial-by-trial learning over extended visual search experiences. Talk presented at the annual meeting of the Vision Sciences Society, St. Pete Beach, FL.

Ericson, J. M., & Mitroff, S. R. (in preparation). Long-term visual search: Learning in search to achieve proficiency.

Ericson, J. M., Mitroff, S. R., & Sharpe, B. (2016, September). Long-term visual search: Using mobile app “big data” to reveal key aspects of experience in visual search. Paper presented at the annual meeting of the Human Factors & Ergonomic Society, Washington D.C.

This work represents a combination of several aspects of our ARO project—we used in-lab data and big data from the mobile

app to understand how performance develops with exposure and with time. Our focus was on understanding how expertise develops and what factors influence learning. One clear finding is that early performance in the smartphone game is a strong predictor of later performance. This is an intriguing result that may speak to ingrained performance differences. There are many promising aspects, and we are currently preparing several manuscripts. This work will continue into the subsequent ARO at George Washington University.

Technology Transfer