Applied Cognitive Psychology, *Appl. Cognit. Psychol.* (2014)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/acp.3083

Improving the Efficacy of Security Screening Tasks: A Review of Visual Search Challenges and Ways to Mitigate Their Adverse Effects

ADAM T. BIGGS* and STEPHEN R. MITROFF

Department of Psychology & Neuroscience, Center for Cognitive Neuroscience, Duke University, Durham, USA

Summary: Security checkpoints are used to keep potentially dangerous items and individuals out of secure areas. Although technological advances can enhance security efficacy through both accuracy and speed, ultimate success or failure is largely determined by human performance. As such, it is necessary to minimize any shortcomings that stem from the limits of human cognitive abilities. Cognitive performance can be influenced by numerous factors, including those imposed by the search task (e.g., the number of prohibited items) and the basic abilities of the searchers themselves (e.g., competency and experience). Here, we review and discuss four specific challenges of the task itself that can negatively affect the accuracy of a security screening: target visibility, an unknown target set, the possible presence of multiple targets, and low target prevalence. For each, we present the challenge faced and the potential significance of the challenge and then offer possible solutions on the basis of the existing literature. Copyright © 2014 John Wiley & Sons, Ltd.

Security checkpoints, such as those employed at airports, sporting events, schools, and other similar environments, are designed to maintain a secure environment by preventing the introduction of dangerous items and/or individuals. Each checkpoint provides a controlled location where permissible elements can pass through and prohibited elements can be kept out. Although security at each individual checkpoint might have unique components, *visual search*—looking at individuals and their belongings to identify potential threats—is a common denominator. Unfortunately, visual search is fraught with pitfalls that can lead to costly mistakes, and this poses an important threat to security performance (Schwaninger, 2005).

Technological advances have successfully enhanced search performance at checkpoints, and some security screenings depend largely upon information obtained by nonhumans. For example, explosive material can be detected both by sensors (e.g., Singh, 2007) and trained animals (e.g., Furton & Myers, 2001). However, whereas significant advances in technology have increased success rates (e.g., von Bastian, Schwaninger, & Michel, 2008; Michel & Schwaninger, 2009), the human element remains a pivotal link for most security screening tasks (Schwaninger, 2006). As such, security screening is subject to the shortcomings of human performance, and it is critical to understand what challenges are imposed upon the searcher by almost any security screening. Notably, there is an important difference between shortcomings imposed by the task itself and shortcomings that arise because of relevant abilities of a particular individual—such as competency and fatigue. Here we focus on the former rather than the latter source of shortcomings—assessing some of the challenges to human visual search that are imposed by the security screening task. Specifically, we discuss four prominent challenges: target visibility, unknown target set, multiple targets, and low target prevalence. There are obviously additional factors that can impact performance, although these four are representative of the breadth and magnitude for the known challenges. Below we provide a brief description of these four challenges, some known factors about the magnitude of the related problems, and corresponding solutions in the existing literature. These challenges have life-or-death implications, and by examining their conceivable solutions, it may be possible to mitigate their influences.

Correspondence to: Adam T. Biggs, Center for Cognitive Neuroscience, B203 LSRC, Box 90999, Duke University, Durham, NC 27708, USA. E-mail: adam.biggs@duke.edu

TARGET VISIBILITY

The challenge

One of the most obvious challenges in any security screening task is that some targets are relatively difficult to find (see Figure 1 for illustrations). This distinction is due, in part, to the intent of individuals passing through a security checkpoint. Some individuals intend to sneak contraband through a checkpoint and will therefore make an item (or themselves) difficult to identify. For example, a potential terrorist going through an airport security checkpoint may conceal contraband in the lining of a bag. This example is strikingly different than individuals accidentally bringing contraband through a checkpoint; for example, someone might forget a knife in their bag and leave it prominently displayed atop other items. The key difference between these scenarios, as far as security screening personnel need be concerned, is that some items are likely to be well-hidden and some are likely to be quite exposed. Here we discuss several factors relevant to security screenings, which affect an item's visibility. These various examples best describe the general problem as opposed to forming an exhaustive list of every way a target could be hidden or obscured.

First, an item can stand out because of its physical distinctiveness in a display (Bolfing, Halbherr, & Schwaninger, 2008; Schwaninger, 2003; Schwaninger, Hardmeier, & Hofer, 2004; Schwaninger, Michel, & Bolfing, 2007). For example, the items in the top row of Figure 1 are relatively easy to detect when unobstructed, yet difficult to identify with additional items crowding and occluding them (as in the bottom row of Figure 1; see Figure 2 for enlarged examples of Figure 1). Physical distinctiveness can also be affected by an item's material properties. For example, airport security X-ray machines distinguish material types by color

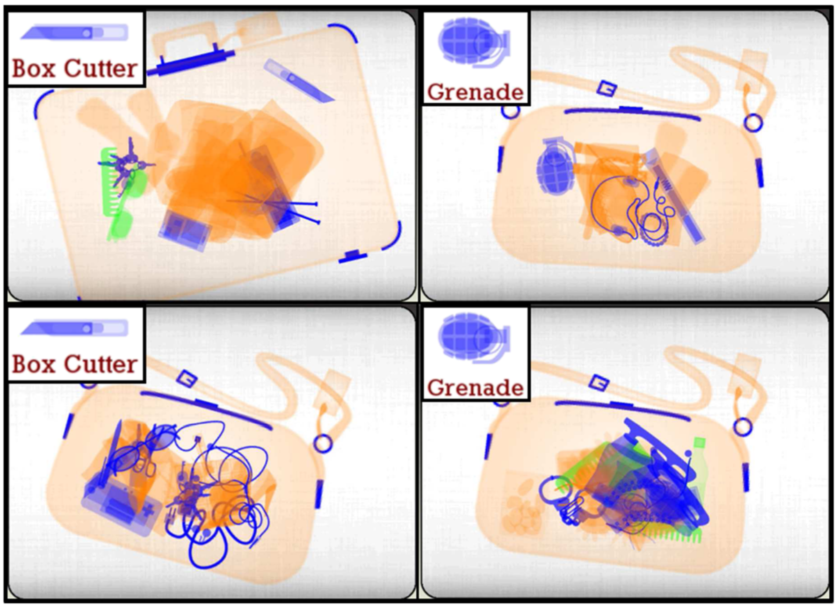

Figure 1. Examples of how the same target item can be readily seen (top row) or well-hidden (bottom row). The target item in the left column images is a box cutter, and the target item in the right column images is a hand grenade (with samples of both isolated in the corner of each image). See Figure 2 for close-ups of the targets in the bottom row. All images are taken, with permission, from the mobile application *Airport Scanner*, and bag depictions are meant to mimic airport security searches without using actual X-ray images

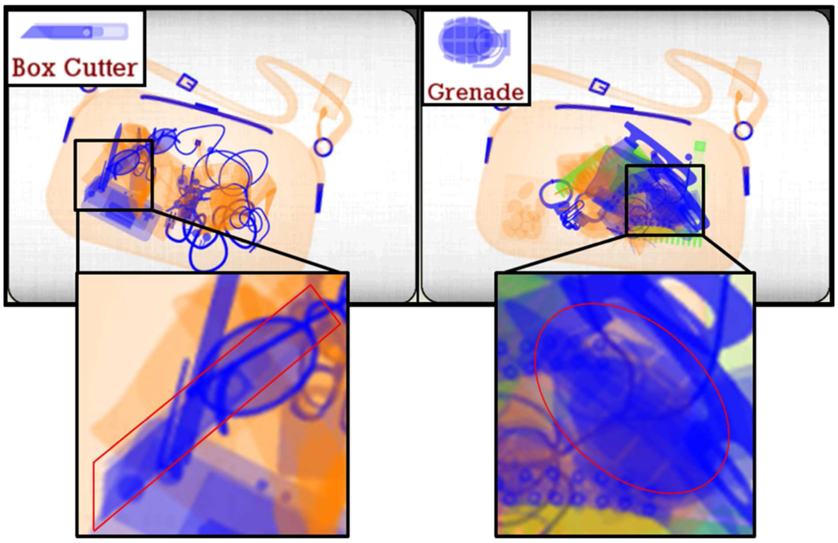

Figure 2. Close-ups of well-hidden targets from Figure 1

(e.g., organic materials appear orange), and an item made in an atypical material may be harder to detect as it will appear in the 'wrong' color (see Figure 3). This instance is particularly important in the case of firearms, which are typically metallic but could also contain nonmetallic components. The operational relevance of this point is clearly demonstrated in the issue of laptops inside bags during X-ray screenings—a laptop can obscure the contents of a bag, making other items difficult to identify (Mendes, Schwaninger, & Michel, 2013).

Second, an item's visibility can be affected by its physical orientation—for example, someone might intentionally place a prohibited item at a specific orientation as objects can be more difficult to detect when viewed from an unusual, noncanonical viewpoint (Bolfing et al., 2008; Koller, Hardmeier, Michel, & Schwaninger, 2008; Schwaninger, 2006; Schwaninger et al., 2004). In an X-ray image, a knife viewed from the side will likely be easier to identify than a knife viewed such that the base is aimed at the screener; one image readily appears as a knife, whereas the latter image could appear as a block of metal.

Third, an item can stand out because of the other items surrounding it; for example, illegal drugs would be less salient when placed among legal prescription drugs than when in isolation. Attention research has established that 'target–distractor similarity'—how physically similar the target is to nontarget items—can dramatically impact visual search performance (e.g., Duncan & Humphreys, 1989; Neider, Boot, & Kramer, 2010), and so something illegal could be difficult to find when placed among physically or conceptually similar legal items.

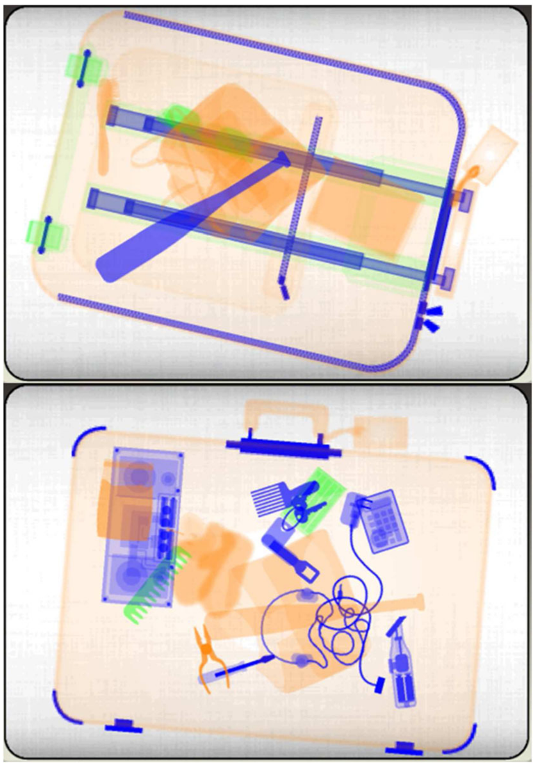

Figure 3. Examples of two different baseball bats: one with high target visibility (top, metallic baseball bat colored blue) and one with low target visibility (bottom, wooden baseball bat colored orange). In the *Airport Scanner* game, the blue bat is detected approximately 92% of time when the orange bat is detected approximately 15% of the time (Biggs, Adamo, & Mitroff, 2014)

The significance

Poor target visibility could impact search performance such that target items may not be found quickly, or worse, not be found at all. Existing evidence suggests that this is exactly the case as high-salience targets are easier to detect than low-salience targets—where salience is defined through contrast differences in the display with high salience indicating easy-to-see targets and low salience indicating difficult-to-see targets (e.g., Biggs & Mitroff, 2014, in press; Cain & Mitroff, 2013; Clark, Cain, Adcock, & Mitroff, 2014; Fleck, Samei, & Mitroff, 2010). These targets were identical in shape and size and never occluded by another item, yet merely making some targets stand out less against the background substantially reduced how often they were found. Although it is generally troubling that well-hidden or occluded items are more likely to be missed than readily visible items, the problem is only compounded by any volitional attempt to camouflage or occlude an object (Neider & Zelinsky, 2006).

The solutions

As one of the more prominent issues facing security screening, target visibility has received a substantial amount of attention. For example, searchers are trained to identify objects from a wide variety of noncanonical viewpoints (e.g., Koller et al., 2008), such as a knife rotated with the base aimed at the screener. Effective training regimens for identifying prohibited items and breaking camouflage remain a continuing area of research (e.g., Boot, Neider, & Kramer, 2009; Chen & Hegdé, 2012), and these efforts should help improve future performance. In addition, implementing a few specific procedural efforts may be highly effective. For example, some airports have security personnel physically rotate bags, which prevents passengers from determining how the inside contents will be viewed. Likewise, multiview X-ray systems can provide multiple images of the same bag, making it especially difficult for smugglers to ensure that a prohibited item will only be viewed from a noncanonical viewpoint or occluded by another item (von Bastian, Schwaninger, & Michel, 2008). More recent technology utilizes three-dimensional, rotatable images to enhance the multiview idea (Mendes et al., 2013). Finally, pseudocoloring—applying nonrealistic color in scans to help differentiate items—can significantly improve search accuracy (i.e., how often a target is found when one appears) by making certain items stand out (Abidi, Zheng, Gribok, & Abidi, 2006). Taken together, the right combination of training, procedure, caution, and technology can prevent even well-hidden contraband from passing through a security checkpoint.

UNKNOWN TARGET SET

The challenge

Security personnel often do not have precise knowledge about what potential contraband will pass through a checkpoint on any given day. Even in relatively constrained security settings, such as entry into sporting events, the potential targets include an unconstrained set of items. For example, most security screenings prohibit firearms, but a ‘firearm’ can come in many sizes, shapes, and colors. This lack of specific information is potentially dangerous given that visual search performance benefits from detailed information (Vickery, King, & Jiang, 2005). Specifically, if searchers are trying to find a firearm, then they would be less accurate if told to look for a handgun than if told to search for a .44 Magnum. Even if the criteria were defined as keeping all firearms from passing through security, two firearms can be considerably different from one another—such as a handgun versus an assault rifle.

The significance

It is important to understand how search accuracy and efficiency are impacted by variability in target items given that a searcher must look for multiple items simultaneously. Research has shown that searching for two dissimilar targets, compared to searching for one target, can hinder accuracy, slow responses, and impair attentional guidance (e.g., Menneer, Cave, & Donnelly, 2009; Stroud, Menneer, Cave, & Donnelly, 2012). Security screenings often prohibit more than just two things, which makes this problem even more distressing. The end result is a cost to search efficacy, which could manifest as a decline in search accuracy or a substantial increase in the time needed to complete the search. However, this challenge does not impose an insurmountable problem as the cost of searching for multiple items is not a purely linear effect (Wolfe, 2012). Individuals are capable of searching for many different items with a logarithmic increase in their cost such that the additional burden in searching for two items versus one item is greater than the additional burden in searching for 22 items versus 21 items.

The solutions

Previous evidence has suggested that dividing a search among multiple searchers can limit the cost of searching for more than one target category (e.g., Menneer et al., 2007). For example, rather than having one screener search for guns and explosive devices, two different screeners could individually search for either guns or explosives, respectively. This division of labor could provide more accurate and efficient search as the possible target set becomes limited, but this approach introduces other pragmatic difficulties—including an increase in manpower and the lingering ambiguity that searching for firearms is not as refined as searching for a .44 Magnum. The increase in manpower may not be unmanageable as each individual may finish the assigned search more quickly than one person searching for different target categories, although it remains unclear how any lingering ambiguity in category items would affect a multiple-searcher system.

Alternatively, effective search strategies and training can counter the memory burden imposed by an unknown target set. For example, someone may choose to visually search a bag as though reading through a book (i.e., left-to-right in rows, starting from the upper left). Search strategy is important because professional searchers who utilize consistent search behaviors (i.e., using the same strategy from one search to the next) show increased accuracy relative to less consistent searchers (Biggs, Cain, Clark, Darling, & Mitroff, 2013; Biggs & Mitroff, 2014). If searchers were to randomly scan each display (i.e., starting from some random point each time and then move to another point with no set order), then there is an additional cognitive burden of remembering where search has and has not been conducted. If individuals consistently use the same strategy, then it may be easier for them to remember where search has and has not been conducted at any point during the task. In turn, the searcher can allocate cognitive resources that would have been expended on memory to object recognition—thus increasing the likelihood of identifying prohibited items.

MULTIPLE TARGETS APPEARING IN A SINGLE SEARCH ARRAY

The challenge

During a security screening task, more than one prohibited item could be present in a single search array. For example, a given carry-on bag at the airport could contain both a water bottle *and* a gun. The presence of multiple targets thus introduces unique challenges that are not present in a single-target search task. Namely, finding one target can cause searchers to miss additional targets when they resume searching. This particular type of search error was originally referred to as 'satisfaction of search' (Smith, 1967; Tuddenham, 1962), although these errors have more recently been referred to as 'subsequent search misses' (SSM; Adamo, Cain, & Mitroff, 2013). As an example of an SSM error, consider the search display in the upper right of Figure 1 with the hand grenade as a target. Most people will readily see the hand grenade, but did you notice the other weapon present in the bag (see Figure 4)?

Several different mechanistic accounts of SSM errors have been offered, and it appears that there are multiple contributing causes rather than a single source (Cain, Adamo, & Mitroff, 2013). The initial explanation—and the source of the original name—was that searchers stopped searching because they became 'satisfied' with the meaning of an image after locating a first target (Smith, 1967; Tuddenham, 1962). However, recent evidence has demonstrated that searchers continue to look through the display after finding a target (Berbaum et al., 1991; Fleck et al., 2010). Another explanation is a perceptual set bias, which argues that searchers are more likely to miss subsequent targets if those targets are not consistent with the found target (Berbaum, Franken, Caldwell, & Schartz, 2010). A searcher who finds a water bottle may become biased toward searching for additional water bottles and will miss a dissimilar target, such as a gun. Additionally, there is a resource depletion argument (Berbaum et al., 1991; Cain & Mitroff, 2013), which suggests that maintaining the location and identity of a found target places a burden on cognitive resources such as attention and working memory. This burden then limits the amount of resources available during the continued search.

The significance

Some estimates suggest that SSM errors may account for one fifth to one third of radiological errors (Anbari, 1997; Berbaum et al., 2010; Krupinski, 2010) and a significant portion of errors in emergency medicine (Kuhn, 2002; Voytovich, Rippey, & Suffredini, 1985). Previous evidence has also demonstrated that professional security screeners are not only vulnerable to SSM errors but that they might be more likely to commit SSM errors than nonprofessional searchers (Biggs & Mitroff, 2013). One reason for the pervasiveness of SSM errors is that they can be increased by a wide variety of situational factors—such as time pressure (Fleck et al., 2010), a searcher's understanding about when they will be finished searching for the day (i.e., the shift lasts either for a

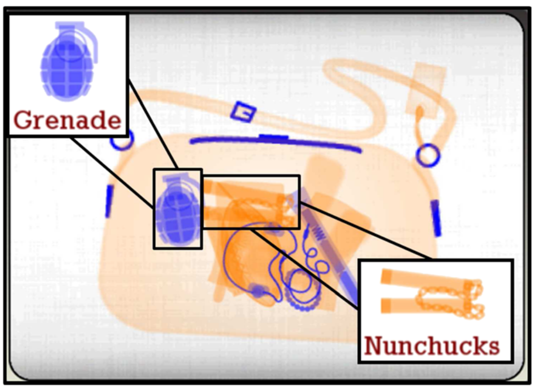

Figure 4. Hand grenade search from Figure 1 with additional target highlighted

set time period, as in airport security screening, or searching for a set number of cases, as in radiology; Clark, Cain, Adcock, & Mitroff, 2014), and anxiety imposed by specific circumstances (Cain, Dunsmoor, LaBar, & Mitroff, 2011).

The solutions

Multiple-target search errors can be addressed by altering the external pressures on the searcher and/or the standard operating procedures of the search. External pressures, such as strict time limits, should be alleviated when possible to promote higher accuracy. Simple procedural changes could also be effective in achieving these goals. For example, searchers exhibit significantly more SSM errors when conducting search for a fixed number of cases—as is typical in many radiological practices—compared to when conducting search for a fixed time period—as in airport security screening (Clark et al., 2014). Likewise, how searchers perceive their task and the targets to be found are critically important elements. If a searcher, particularly a professional searcher, treats a found target with a measure of nonchalance (i.e., that oversized water bottle is not actually dangerous), then this lenience could have the adverse effect of inducing more errors during search after the found target (Biggs & Mitroff, in press). Thus, simple procedural differences—along with a searcher's mindset—might substantially impact search accuracy.

Another solution to the problem of multiple targets is a simple approach of rerunning any bag containing a contraband item after removing the found target. Rerunning a search display has been shown to produce fewer SSM errors by effectively turning one multiple-target visual search into several single-target visual searches (Cain, Biggs, Darling, & Mitroff, 2014). A rerun procedure eliminates the memory burden of a found target, similar to if the target were highlighted or removed in an ongoing search (Cain & Mitroff, 2013). The searcher might effectively treat the display as a new search rather than the continuation of an old one, and this procedure could be doubly effective if a new individual were to conduct the rerun search. This approach is arguably the most direct and easily implemented procedure for reducing errors in multiple-target search.

LOW TARGET PREVALENCE

The challenge

Cognitive psychology experiments often have searchers make decisions about the presence or absence of a target on any given trial where, over the course of the experiment, half (or more) of the trials have a target present. This approach is useful for investigations of cognitive phenomena, yet it does not adequately reflect a factor of critical real-world searches; specifically, 50% target prevalence is a remarkably high number when compared to 'rare-target' searches where a target seldom appears. For example, the cancer rate in mammography screenings has been estimated as 4.69 cancers per 1000 examinations (~0.5% of cases examined; NCI-funded Breast Cancer Surveillance Consortium, 2009). Specific rates of prohibited items in airport security screenings are not public information, although it is reasonable to assume that security screening is also a rare-target search.

The significance

Visual search is subject to the Low Prevalence effect (Wolfe, Horowitz, & Kenner, 2005), which suggests that accuracy decreases when targets are rarely present during search. Some research suggests that this effect is due to a criterion shift in decision-making (i.e., are searchers more likely to say a target is present or more likely to say a target is absent) as searchers become more biased to miss rather than locate a target when one is present (Godwin et al., 2010; Wolfe et al., 2007; but see also Fleck & Mitroff, 2007). Low target prevalence can be a particularly potent influence, and this effect impacts even professional visual searchers, including radiologists (Evans, Birdwell, & Wolfe, 2013) and airport security screening trainees (Wolfe, Brunelli, Rubinstein, & Horowitz, 2013).

Beyond the Low Prevalence effect, there is a similar, but orthogonal, phenomenon related to how often a *specific* target item might appear during search. Regardless of the overall prevalence (what percentage of cases contain any target), there is also variability in specific target frequency (what percentage of target-present cases contains a specific target). For example, cancerous markers might only appear in 0.5% of routine exams (i.e., there is a 0.5% prevalence rate), but a given cancerous marker could be an order of magnitude rarer; architectural distortions, a specific cancerous marker, represent 9% of cancers (Sickles, 1986) and are therefore only present in approximately 0.045% of all routine exams. Previous evidence has demonstrated a strong logarithmic relationship between specific target frequency and search accuracy such that items with low frequency rates are more likely to be missed compared to items with a relatively higher frequency rate (Mitroff & Biggs, 2014). Specifically, in a search environment with an approximate prevalence rate of 50% (i.e., roughly half of the cases contained a target) accuracy was relatively high (92%) for the specific items that appeared on at least 1% of trials, whereas accuracy was very poor (27% accurate) for the items that appeared on less than 0.15% of trials. Low frequency targets present a serious challenge to security screeners as the likelihood of finding a target decreases substantially if the likelihood of that target appearing is below 1%.

The solutions

The Low Prevalence effect can partially be overcome by artificially including a short burst of high prevalence search with feedback prior to longer periods of low prevalence search without feedback (Wolfe et al., 2007). Because accuracy might be poor in low prevalence search due, in part, to a criterion shift of decision-making, a short burst of high prevalence search with clear information about what is correct and incorrect can alter searchers' criteria to a more effective state. These artificially high prevalence trials could be tailored to specific targets to simultaneously counteract overall target prevalence as well as specific target frequency. In practice, this solution is similar to the Threat Image Projection protocol (Hofer & Schwaninger, 2005), where threatening images are digitally projected into bags at airport checkpoints. Although this program assesses performance in a scenario where actual performance is impossible to truly measure (i.e., security screening personnel will never actually know what successfully smuggled items they have missed), it could also be used systematically to address issues of target frequency. For example, the items randomly projected into bags could be proportioned such that very rare and dangerous items are the ones most likely to be projected into bags to artificially increase the overall frequency with which those items appears.

SUMMARY

The present discussion covered four prominent challenges imposed by a security screening task (target visibility, unknown targets, multiple targets, and low target prevalence) along with several methods for addressing those issues. Note that the suggested methods were largely derived through laboratory-based experimentation, and proper control must be applied to translate these ideas into operationally relevant solutions (Clark, Cain, Adamo, & Mitroff, 2012). More broadly though, these challenges are inherent with almost any security screening task, and so it matters little who the specific searcher happens to be—he or she will have to confront and overcome these challenges. Each individual challenge levies a significant burden on the searcher, yet these challenges are by no means insurmountable if the organizations creating the standard operating procedure and the searchers themselves are aware of the issues and how to counter them. The end result can be a marked improvement in search accuracy and efficiency when proper training and procedures are implemented. Technology may improve search accuracy, but the human element is ultimately the weakest—or the strongest—link in security screening (Schwaninger, 2006).

ACKNOWLEDGEMENTS

We thank Ben Sharpe and Kedlin Company for permission to use *Airport Scanner* images and Stephen Adamo and Jonathan Winkle for helpful comments.

REFERENCES

Abidi, B. R., Zheng, Y., Gribok, A. V., & Abidi, M. A. (2006). Improving weapon detection in single energy X-ray images through pseudocoloring. *IEEE Transactions on Systems, Man, and Cybernetics Part C: Applications and Reviews*, *36*, 784–796.

Adamo, S. H., Cain, M. S., & Mitroff, S. R. (2013). Self-induced attentional blink: A cause of errors in multiple-target visual search. *Psychological Science*, *24*, 2569–2574.

Anbari, M. M. (1997). Cervical spine trauma radiography: Sources of false-negative diagnoses. *Emergency Radiology*, *4*, 218–224.

Berbaum, K. S., Franken, E. A., Jr., 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: Cambridge University Press.

Berbaum, K. S., Franken, E. A., Jr., Dorfman, D. D., Rooholamini, S. A., Coffman, C. E., Cornell, S. H., … Smith, T. P. (1991). Time course of satisfaction of search. *Investigative Radiology*, *26*, 640–648.

Biggs, A. T., Adamo, S. H., & Mitroff, S. R. (2014). Rare, but obviously there: Effects of target frequency and salience on visual search accuracy. *Acta Psychologica*, *152*, 158–165.

Biggs, A. T., Cain, M. S., Clark, K., Darling, E. F., & Mitroff, S. R. (2013). Assessing visual search performance differences between Transportation Security Administration Officers and nonprofessional searchers. *Visual Cognition*, *21*, 330–352.

Biggs, A. T., & Mitroff, S. R. (2014). Different predictors of multiple-target search accuracy between nonprofessional and professional visual searchers. *Quarterly Journal of Experimental Psychology*, *67*, 1335–1348.

Biggs, A. T., & Mitroff, S. R. (in press). Differences in multiple-target visual search performance between non-professional and professional searchers due to decision-making criteria. *British Journal of Psychology*.

Bolfing, A., Halbherr, T., & Schwaninger, A. (2008). How image based factors and human factors contribute to threat detection performance in X-ray aviation security screening. In A. Holzinger (Ed.), *HCI and usability for education and work* (pp. 419–438). Berlin: Springer.

Boot, W. R., Neider, M. B., & Kramer, A. F. (2009). Training and transfer of training in the search for camouflaged targets. *Attention, Perception, & Psychophysics*, *71*, 950–963.

Cain, M. S., Adamo, S. H., & Mitroff, S. R. (2013). A taxonomy of errors in multiple-target visual search. *Visual Cognition*, *21*, 899–921.

Cain, M. S., Biggs, A. T., Darling, E. F., & Mitroff, S. R. (2014). A little bit of history repeating: Splitting up multiple-targets visual searches decreases second-target miss errors. *Journal of Experimental Psychology: Applied*, *20*, 112–125.

Cain, M. S., Dunsmoor, J. E., LaBar, K. S., & Mitroff, S. R. (2011). Anticipatory anxiety hinders detection of a second target in dual target search. *Psychological Science*, *22*, 866–871.

Cain, M. S., & Mitroff, S. R. (2013). Memory for found targets interferes with subsequent performance in multiple-target visual search. *Journal of Experimental Psychology: Human Perception & Performance*, *39*, 1398–1408. doi: 10.1037/a0030726

Chen, X., & Hegdé, J. (2012). Learning to break camouflage by learning the background. *Psychological Science*, *23*, 1395–1403.

Clark, K., Cain, M. S., Adamo, S. H., & Mitroff, S. R. (2012). Overcoming hurdles in translating visual search research between the lab and the field. In *The influence of attention, learning, and motivation on visual search* (pp. 147–181). New York: Springer.

Clark, K., Cain, M. S., Adcock, R. A., & Mitroff, S. R. (2014). Context matters: The structure of task goals affects accuracy in multiple-target visual search. *Applied Ergonomics*, *45*, 528–533.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*, 433–458.

Evans, K. K., Birdwell, R. L., & Wolfe, J. M. (2013). If you don't find it often, you often don't find it: Why some cancers are missed in breast cancer screening. *PLoS One*, *8*, e64366.

Fleck, M. S., & Mitroff, S. R. (2007). Rare targets are rarely missed in correctable search. *Psychological Science*, *18*, 943–947.

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*, 60–71.

Furton, K. G., & Myers, L. J. (2001). The scientific foundation and efficacy of the use of canines as chemical detectors for explosives. *Talanta*, *54*, 487–500.

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.

Hofer, F., & Schwaninger, A. (2005). Using threat image projection data for assessing individual screener performance. *WIT Transactions on the Built Environment*, *82*, 417–426.

Koller, S.M., Hardmeier, D., Michel, S., & Schwaninger, A. (2008). Investigating training, transfer and viewpoint effects resulting from recurrent CBT of X-ray image interpretation. *Journal of Transportation Security*, *1*(2), 81–106.

Krupinski, E. A. (2010). Current perspectives in medical image perception. *Attention, Perception, & Psychophysics*, *72*, 1205–1217.

Kuhn, G. J. (2002). Diagnostic errors. *Academic Emergency Medicine*, *9*, 740–750.

Mendes, M., Schwaninger, A., & Michel, S. (2013). Can laptops be left inside passenger bags if motion imaging is used in X-ray security screening? *Frontiers in Human Neuroscience*, *7*, 1–10.

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*, 915–932.

Menneer, T., Cave, K. R., & Donnelly, N. (2009). The cost of search for multiple targets: The effects of practice and target similarity. *Journal of Experimental Psychology: Applied*, *15*, 125–139.

Michel, S., & Schwaninger, A. (2009, October). Human-machine interaction in X-ray screening. In *43rd Annual International Carnahan Conference on Security Technology*, pp. 13–19.

Mitroff, S. R., & Biggs, A. T. (2014). The ultra-rare-item effect: Visual search for exceedingly rare items is highly susceptible to error. *Psychological Science*, *25*, 284–289.

NCI-funded Breast Cancer Surveillance Consortium co-operative agreement (U01CA63740, U01CA86076, U01CA86082, U01CA63736, U01CA70013, U01CA69976, U01CA63731, U01CA70040). (2009). Downloaded 05/20/2013 from the Breast Cancer Surveillance Consortium Web site -http://breastscreening.cancer.gov/data/performance/screening/2009/rate_age.html

Neider, M. B., Boot, W. R., & Kramer, A. F. (2010). Visual search for real world targets under conditions of high target–background similarity: Exploring training and transfer in younger and older adults. *Acta Psychologica*, *134*, 29–39.

Neider, M. B., & Zelinsky, G. J. (2006). Searching for camouflaged targets: Effects of target-background similarity on visual search. *Vision Research*, *46*, 2217–2235.

Schwaninger, A. (2003). Evaluation and selection of airport security screeners. *AIRPORT*, *02/2003*, 14–15.

Schwaninger, A. (2005). Increasing efficiency in airport security screening. *WIT Transactions on the Built Environment*, *82*, 407–416.

Schwaninger, A. (2006, November). Airport security human factors: From the weakest to the strongest link in airport security screening. In *Proceedings of the 4th International Aviation Security Technology Symposium*, Washington, DC, USA, pp. 265–270.

Schwaninger, A., Hardmeier, D., & Hofer, F. (2004). Measuring visual abilities and visual knowledge of aviation security screeners. *IEEE ICCST Proceedings*, *38*, 258–264.

Schwaninger, A., Michel, S., & Bolfing, A. (2007). A statistical approach for image difficulty estimation in X-ray screening using image measurements. In *Proceedings of the 4th Symposium on Applied Perception in Graphics and Visualization*, ACM Press, New York, USA, 123–130.

Sickles, E. A. (1986). Mammographic features of 300 consecutive nonpalpable breast cancers. *American Journal of Roentgenology*, *146*, 661–663.

Singh, S. (2007). Sensors—An effective approach for the detection of explosives. *Journal of Hazardous Materials*, *144*(1), 15–28.

Smith, M. J. (1967). *Error and variation in diagnostic radiology*. Springfield, IL: Thomas.

Stroud, M. J., Menneer, T., Cave, K. R., & Donnelly, N. (2012). Using the dual-target cost to explore the nature of search target representations. *Journal of Experimental Psychology: Human Perception and Performance*, *38*, 113–122.

Tuddenham, W. J. (1962). Visual search, image organization, and reader error in roentgen diagnosis. *Radiology*, *78*(5), 694–704.

Vickery, T. J., King, L., & Jiang, Y. (2005). Setting up the target template in visual search. *Journal of Vision*, *5*, 81–92.

von Bastian, C. C., Schwaninger, A., & Michel, S. (2008). Do multiview X-ray systems improve X-ray image interpretation in airport security screening? *Zeitschrift für Arbeitswissenschaft*, *3*, 166–173.

Voytovich, A. E., Rippey, R. M., & Suffredini, A. (1985). Premature conclusions in diagnostic reasoning. *Academic Medicine*, *60*, 302–307.

Wolfe, J. M. (2012). Saved by a log: How do humans perform hybrid visual and memory search? *Psychological Science*, *23*, 698–703.

Wolfe, J. M., Brunelli, D. N., Rubinstein, J., & Horowitz, T. S. (2013). Prevalence effects in newly trained airport checkpoint screeners: Trained observers miss rare targets, too. *Journal of Vision*, *13*(3), 33.

Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). Rare items often missed in visual searches. *Nature*, *435*(May), 6–7.

Wolfe, J. M., Horowitz, T. S., Van Wert, M. J., Kenner, N. M., Place, S. S., & Kibbi, N. (2007). Low target prevalence is a stubborn source of errors in visual search tasks. *Journal of Experimental Psychology: General*, *136*, 623–638.

