The role of human factors in airport baggage screening

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Abstract

We all spend much time visually scanning our surrounding environment. Visual searching is particularly crucial for public safety when it comes to those occasions that can have fatal consequences. Human factors that influence decision-making in target detection are, however, widely considered as determinants for whether there are prohibited items or not. Cognitive performance of security screening can be influenced by the experiences of the searcher, but also can be affected by the task itself, which is closely associated with principles of perception, visual attention and working memory. This paper critically examines five aspects of the searching task: low target salience; the unknown target set; simultaneous search for all types of targets; the possible occurrence of multiple targets; and low target prevalence. It highlights the challenges of baggage screening and proposes two means for improving the accuracy and the efficiency of the task: operational strategies and off-the-job training. Further studies are needed to confirm whether those strategies could strike a balance between efficacy and efficiency for airport baggage screening in a real-life setting.

Introduction

Whether looking for a mobile phone at home, a file in the folder, or a friend in the crowd, 'much of our life is spent searching for information relevant to the task in hand' (Peterson, Kramer, Wang, Irwin, & McCarley, 2001). When search tasks have life-or-death implications, it is imperative to underscore that the screener performs a search with greater accuracy and efficiency. Baggage screenings at airports constitute a critical search task. While the efficiency of baggage scanning has been significantly improved in both accuracy and speed by technological advances (e.g., X-ray scanning), the ultimate outcome (e.g. the missing rate of the target) is largely attributed to human factors (Biggs & Mitroff, 2014). Paradoxically, the screener is either the strongest or weakest link for most of the screening tasks (Schwaninger, 2006). Currently, it is still not feasible to have such an advanced artificial detection system that can detect the illicit items as quickly and reliably as humans do (Schwaninger, 2005, 2006).

A baggage screener's task is to identify the prohibited items (the target) on an X-ray display that contains a number of other items (the distractors), a procedure requiring attention and working memory (Goldstein, 2010). As the task itself greatly influences cognitive performance in baggage scanning, each component of the task will be discussed in turn: 1) low target salience; 2) the unknown target set; 3) simultaneously searching for all types of targets; 4) the possible occurrence of multiple targets; and 5) low target prevalence. In doing so, the paper uses a cognitive-psychological approach to highlight the challenges that these task components present for baggage screeners. It offers two types of procedural solutions for improving object recognition and visual attention that do not excessively undermine the efficiency of baggage screening: operational strategies and off-the-job training.

Target salience

Target salience can be enhanced by employing visual cues and camouflaged targets training, and having security staff physically rotate bags prior to screening. Low visibility of the banned items in airport security screening is attributed to three challenging target-based factors: physical distinctiveness; physical orientation; and target–nontarget similarity (Biggs, Adamo, & Mitroff, 2014; Biggs & Mitroff, 2014; Schwaninger, 2005). First, the visibility of the target has been heavily determined by its physical distinctiveness (e.g., shape and size) in a display (Schwaninger, Michel, & Bolfing, 2007). The material proprieties of a target largely interact with the physical identity, which could make it stand out from the screening image. This is attributed to X-ray screening machines mainly differentiating material types by pseudocolouring, such as light orange indicating non-metallic material (see Figure 1).

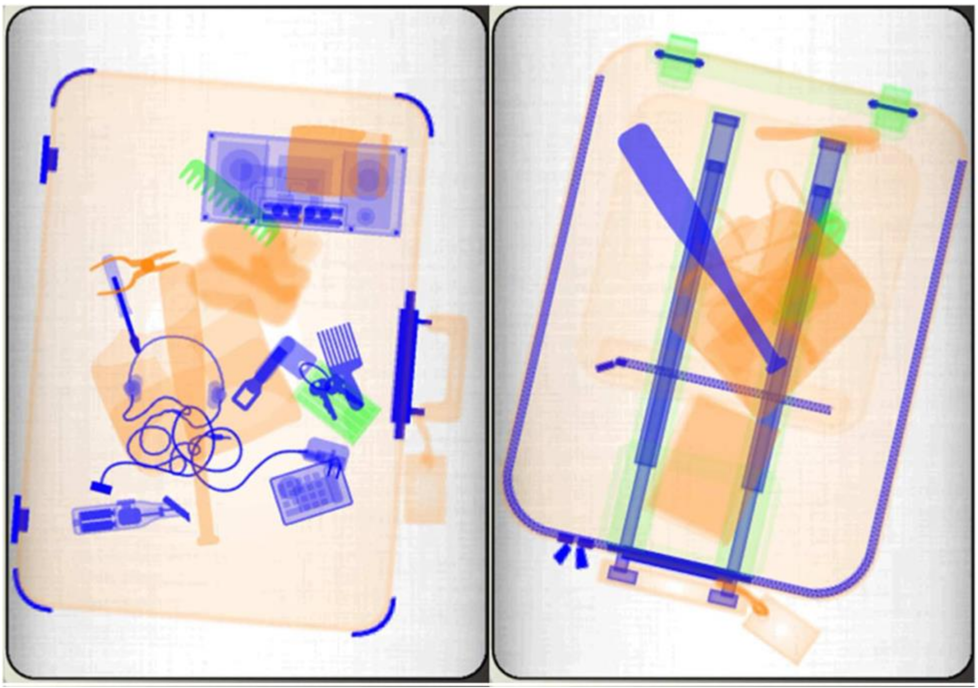

Figure 1: Examples of two different baseball bats: one with lower target visibility (left, wooden baseball bat, coloured light orange) and one with higher target visibility (right, metallic baseball bat, coloured blue)

Source: Biggs et al., 2014.

To mitigate the problem with physical distinctiveness when looking at the baggage image, an operational adjustment and a routine exercise are proposed. That is, setting up a target template provided with detailed visual rather than semantic information, and separating targets from the background via camouflaged target training (Chen & Hegdé, 2012; Vickery, King, & Jiang, 2005). Instead of giving a list of named prohibited items to the screeners, providing detailed visual cues may be more informative. For example, Vickery et al.'s (2005) study not only stressed the importance of prior knowledge of the target in a visual search but also highlighted that the reaction time of a visual cue will be faster than a semantic cue when accuracy is comparable. Matching the target with a specific template (mental representation), however, could compromise the efficiency of visual search (Bravo & Farid, 2014).

The target–background similarity could also profoundly influence a target's physical distinctiveness. In many real-world search occasions such like airport baggage screening, targets and distractors are difficult to segment from the background, which becomes an efficiency cost during the visual search (Boot, Neider, & Kramer, 2009). In this case, an X-ray image could contain items that the machine accidentally filters into the background by pseudocolouring (see Figure 1, where the target of the wooden baseball bat has been faded into the background because of its non-metallic material). This is a sound example of how searching for camouflaged targets involves imperfect segmentation between targets and background (Neider, Boot, & Kramer, 2010). There are nonetheless promising studies to improve the training of camouflaged searches (Boot, Neider, & Kramer, 2009; Neider et al., 2010). In one study, camouflaged-trained participants not only demonstrated improved search performance with fast response times in target recognition, but also fewer eye movements when searching novel camouflaged targets (Boot, Neider, & Kramer, 2009).

Considering the viewpoint-dependent theory proposing that the accuracy and speed of object recognition are affected by the changes in viewpoint, the visibility of illegal items could be influenced by the physical orientation (Tarr, 1995; Tarr & Bülthoff, 1995). This often happens when a banned item is intentionally placed in a particular orientation so that screeners are difficult to detect from their points of view (Bolfing, Halbherr, & Schwaninger, 2008). Having security personnel manually rotate bags into certain positions prior to screening, however, could be a viable solution (Koller, Hardmeier, Michel, & Schwaninger, 2008).

The final factor to consider in target salience is the target–distractor similarity. Research on target distractors, such as feature integration theory and subsequent development, highlights how visual task performance is impaired as the similarity between targets and distractors increases and the similarity among non-targets decreases (Duncan & Humphreys, 1989; Treisman & Sato, 1990). The prohibited items are likely to be missed when surrounded by other physically or conceptually similar but permissible items (Duncan & Humphreys, 1989; Proulx & Egeth, 2006). It is imperative to stress the pitfalls of conceptual similarity when looking at two physically similar items during a routine briefing. Illicit drugs would be less detectable when blending in with legally prescribed drugs, or a bottle of water versus a bottle of gasoline (Neider, Boot, & Kramer, 2010). This similarity effect might be modulated by using a decision-tree tool accompanied by a visual template to avoid the conceptual traps, as well as having screeners to categorise the non-targets under the same category during a large set-size task. The downside of these procedures is the prolonged searching time as priming effects do occur when targets are absent (Wilschut, Theeuwes, & Olivers, 2014).

Unknown target set

To deal with the problem of the unknown target set, off-job training with a diverse category as well as consistent searching strategies appear to be promising. The unknown target set is twofold in the context of airport baggage screening. First, it accounts for security screeners having no prior and specific knowledge about what items they will be looking at during any given scanning task (Vickery, King, & Jiang, 2005). Second, the combination of items during each screening is unknown, such as the features of combination and set sizes (Bolfing et al., 2008). Accordingly, detection training with diverse categories is introduced to ease the former difficulty , since training with variability can improve screeners' abilities to identify novel objects (Gonzalez & Madhavan, 2011). Gonzalez and Madhavan (2011) indicated that training with high diversity of categories (e.g., knives, guns, scissors, glass objects and metal tools) produced: a higher hit rate; a lower rate of false alarms; and a faster detection time during later detection of novel dangerous targets compared with those who were trained with low diversity of categories (e.g., knives only).

Regarding the unknown combination, consistent visual search strategies could be adopted to offset the memory burden imposed by the unknown target set. That is, a short-term memory burden of recalling what area of the image has or has not been attended occurs when a screener randomly scans the display. Biggs, Cain, Clark, Darling, and Mitroff (2013) observed a higher accuracy of target detection in the professional searchers who have consistent searching behaviour (e.g., scanning from left to right in a row with each display), as compared to those who are less consistent. The study underlines the effectiveness of consistent top-down control to visual search improvement. This strategy enables searchers to reallocate their limited cognitive resources from short-term memory to object recognition.

Simultaneously searching for all types of targets

Given that the current practice in X-ray baggage scanning is to implement a screener to search for all types of targets (e.g., knives, guns, drugs and metal tools) simultaneously in each display, both divided attention and selective attention are under strain for possibly missing any subset (Goldstein, 2010). Divided attention is involved in attending simultaneously to two or more spatially separate locations (Goldstein, 2010). Selective attention refers to selectively processing relevant sensory information for enhanced processing while filtering out the irrelevant visual noise (Underwood & Everatt, 1996). Guided baggage searches are more likely to generate certain inference between top-down requirements for each type of target and result in inappropriate target representations (Wolfe, Cave, & Franzel, 1989). The cognitive burden in searching for more than one target category could, however, be reduced via dividing a search among multiple searchers across target types (Menneer, Barrett, Phillips, Donnelly, & Cave, 2007). Instead of having one screener to look for both knives and explosives, it could be more efficacious to have one screener to only search for knives and another screener only look for explosives. Whether or not there is enough staff resources to divide tasks should be considered beforehand.

Possible occurrence of multiple targets

Adopting time flexibility and a rerun search by a different screener can be useful for tackling the possible appearance of multiple targets. When multiple targets appear in a single search array, a searcher who finds one target is likely to miss the remaining targets thereafter. This type of error has been referred to as 'subsequent search misses' (SSM) in cognitive psychology literature (Adamo, Cain, & Mitroff, 2013). Recent findings suggest that SSM errors might be attributed to two underlying mechanisms: the perceptual set bias and depletion of cognitive resources (Fleck, Samei, & Mitroff, 2010). The former mechanism assumes that searchers are more susceptible to SSM when subsequent targets are neither physically nor categorically consistent with the found targets. For example, a screener who found a knife is biased to search for additional knives and may possibly miss a dissimilar target – such as an explosive. Meanwhile, the cognitive resources (e.g., visual attention and working memory) are draining due to constantly tracking the identities and locations of found targets (Adamo et al., 2013; Cain & Mitroff, 2013).

Three operational improvements are recommended for reducing SSM in the likelihood of multiple targets. In Adamo, Cain, and Mitroff's 2015 study, more of these errors were observed while looking for additional targets under time pressure. Therefore, when possible, the adjustment of the strict time limit of the screening task is anticipated to alleviate the adverse effects of SSM. Another simple procedure would be to conduct a second search right after the suspicious items have been found and removed, and having a different screener perform the rescan would further improve detection rate (Cain, Biggs, Darling, & Mitroff, 2014). The efficacy of the rerun is achieved by dividing a multiple-target search into several single-target searches, as the memory burden of found targets can be eased (Cain & Mitroff, 2013). Additionally, a little 'pause' can be added during the screening task because searching a moving display can result in increased SSM errors, as compared to a static image (Stothart, Clement, & Brockmole, 2017).

Low target prevalence

Low-prevalence target effects can be improved by providing a short burst of higher prevalence search with feedback; monetary incentives; and knowledge about misses through false feedback. The finding that rare targets are more likely to be missed, also known as the low-prevalence effect, has received increasing attention from cognitive researchers (e.g., Fleck & Mitroff, 2007; Van Wert, Horowitz, & Wolfe, 2009; Wolfe, Horowitz, & Kenner, 2005). This means that miss rates are much higher when the presence of targets is very infrequent (Fleck & Mitroff, 2007). Compared to the miss rate of 0.09 at the high prevalence of 50 per cent, the miss rate jumped to 0.32 at the low prevalence of 2 per cent (Van Wert, Horowitz, & Wolfe, 2009). This perceptual effect is very robust and persistent in our everyday visual search, despite being subjected to the criterion adjustment of detection (Fleck & Mitroff, 2007).

Essentially, the criterion of baggage screening aims to maximise the likelihood of a 'hit' in searching prohibited items and to minimise the chance of 'miss' (Lynn & Barrett, 2014). This means adopting a liberal criterion for reporting 'yes', even though this sometimes results in a false alarm, and a more conservative criterion for 'no' responses (Lynn & Barrett, 2014). Wolfe et al.'s 2007 study suggested that 'absent' responses of targets are slower than 'present' responses in a high-prevalence search; however, 'absent' responses are faster than 'present' responses in low-prevalence conditions. Contradictory results were presented on whether the effect could be moderated by giving searchers the option to correct their previous response, such as rerunning the bags (e.g., Fleck & Mitroff, 2007 vs Van Wert et al., 2009).

Regardless of such contradictions, there are three alternatives that may help to promote the detection rate in rare target search. First, Wolfe et al. (2007) reported that providing a short burst of higher prevalence search with feedback can encourage searchers to maintain a high-prevalence criterion during a low-prevalence search. For instance, a high-prevalence of the training set with feedback can be presented during the middle of a screener's working shift (Wolfe et al., 2007). This study also highlighted the important effects of change in the monetary incentives on the searchers' criterion for low-prevalence searching (e.g., commissions are associated with the number of prohibited items found) (Wolfe et al., 2007). Further, there is evidence to suggest that more infrequent targets could be detected by increasing the searchers' perceived misses via false feedback (Schwark, Sandry, MacDonald, & Dolgov, 2012).

Conclusion

This paper has employed a cognitive-psychological framework to assess the five significant challenges imposed by airport baggage screening tasks. The difficulty with target salience and the low-prevalence effects constitute the two greatest challenges, due to their inherent complexity compared to the other three. Strategies such as a specific visual template, camouflaged targets training and categorising non-targets could, however, be promising, even though sometimes inefficient. To deal with unknown target set, detection training with diverse categories and consistent visual search strategies are most likely to strike a balance between efficacy and efficiency for baggage screening. The problem with simultaneously searching for all types of targets could be moderated by dividing a search among multiple searchers across target types. Whether there are enough staff resources to do this, though, should be considered.

In order to address the possible appearance of multiple targets, it is advised that airport security adopt a flexible time limit of the screening task and conduct a rerun search by a different screener. The problem of low-prevalence targets could be resolved by employing a short burst of higher prevalence search with feedback. Subsequently, a change in the payoff matrix and heightening the searchers' sensitivity to misses via false feedback could be two other feasible options. Of course, the practicality of these proposed solutions might be constrained as they are mostly derived from laboratory-based studies. Further studies should, therefore, focus on the effectiveness and efficiency of these procedural solutions and training in real-life baggage screening scenarios at the airport. Again, technology may facilitate visual searching and object recognition in general, but when it comes to those inherently complex as well as socially important search tasks, human factors still are the strongest or weakest link in security scanning.

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