Is that a gun? The Influence of Features of Bags and Threat Items on Detection Performance

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An experiment is reported where naïve observers searched 50 X-ray images of air passenger luggage for potential terrorist threat items. For each image their eye movements were recorded remotely and they had to rate their confidence in whether or not a potential threat item was present. The images were separately rated by other naïve observers in terms of; visual complexity of bags, the familiarity and visual conspicuity of threat items. The visual angle subtended by guns and the familiarity of threat items influenced the detection rate. Eye movement data revealed that the complexity of bags and the conspicuity of threat items also influenced visual search and attention.

Introduction

X-ray screening of passengers' luggage at airports is an important way of protecting against terrorism on aeroplanes. However, the effectiveness of detecting and recognizing potential terrorist threat items is determined by the level of human performance that can be achieved. Inevitably such performance is variable and it is important to find methods to both improve and maintain such performance to be consistently high. The key interest lies in maintaining a low false negative error rate so that potential threat items are not missed. What are the visual and cognitive factors of this visual inspection task and what features of luggage bags and threat items influence detection and visual search?

A strong foundation for understanding the airport screeners' task can be found in radiology. Here, visual search studies over the past 30 years have provided a theoretical model to classify search error types based on visual dwell time (Kundel et al, 1978) and models of understanding the detection process (e.g. Swensson, 1980). The first step of visual search of such images is a fast, parallel global scanning stage. Then spatial attention is allocated serially to potential target areas. 'Pop-out' happens if a target is obvious because of simple local properties or other reasons, e.g., size, brightness and contrast. Every selected area is scrutinized by the visuo-cognitive system. Based on eye movement data from various experiments, failure to find a target could result from search, detection or recognition if the target falls within the useful field of view which is defined as the area around the fixation point from which the information is being processed (Mackworth, 1974).

Visual search and detection performance are influenced by familiarity with target features (Kundel & La Follette, 1972) and the size and conspicuity of a target (nodule) - with larger and more conspicuous nodules receiving less visual attention than smaller and less conspicuous nodules (Krupinski et al, 2003). Visual complexity also influences the cognitive processing of pictorial stimuli; more complex stimuli are more difficult to process (Alario & Ferrand, 1999), and detection performance (Schwaninger et al, 2004). Moreover, for successful detection a target requires observers not only scrutinize the appropriate area but also to recognize the target when they look at it even when it is camouflaged.

Two studies are reported here. The first uses eye position recording of naïve observers as they searched X-ray luggage images for threat items such as; guns, knives and improvised explosive devices (IEDs). In the second, other observers, again naïve to the images, evaluated luggage images which contained a threat item using the following variables: visual complexity of bags; familiarity, and visual conspicuity of the threat items. The purpose was to understand the factors underlying the inspection of these complex images by investigating whether or not there was a relationship between the threat and luggage features that people attended to and how such images were perceived by other observers.

Method

Participants

Ten naïve participants (4 female and 6 male) took part in the visual search study. Ten other naïve participants (4 female and 6 male) took part in the evaluation study. They all had no prior knowledge of examining such X-ray images,

Stimuli and Apparatus

Ten participants examined fifty X-ray images of which twenty-five were normal luggage items. The remaining images contained potential threat items, including; guns, knives and IEDs. Five images contained multiple threat items and for all others only one threat item was present - only data for the single threat items are considered here. Participants' eye movements were recorded by a Tobii eye-tracker (X50). They viewed images on a 53cm monitor at a distance of 70cm.

Procedures

Visual search

Participants were first familiarised with the type of images and the procedure. They then examined 50 luggage images in a random order, for an unlimited viewing time. For each image the participant had to rate their confidence in whether or not threat items were present and indicate such threat location in the luggage image (Liu et al, in press).

AOIs

The eye movement data needed to be related to the threat items. The approach taken was to generate an area of interest (AOI) around each threat item and then to consider eye fixation data which fell within each AOI. Given the irregular form of threat items the dimensions of the area of interest (AOI) were determined by: the form of each threat item; the visual angle subtended by the fovea, and the accuracy of the eye-tracker ($0.5\sim0.7^{\circ}$). The foveola is the area of the retina that provides the best visual resolution and subtends a visual angle of about 1.2^{0} (Schwartz, 1994). The AOI was estimated to be an area which had a similar form to the threat item profile, but was 1 cm wider than the edge of the item, which at a viewing distance of 70 cm subtended 1^{0} visual angle.

Raw eye movement data were then grouped into meaningful fixations on the basis of fixation radius and the minimum fixation duration. Fixation radius was set at 2.5^{0} – a typical useful field of view size in medical imaging (e.g. Nodine et al, 1992) and it has been previously shown reasonable to apply this to luggage images (Gale et al, 2000). The dwell time in an AOI was obtained from the fixation clusters on it. These eye position parameters were analysed with the subjective variables detailed in the next section. Other than the relationship between the threat item features and visual search, just how these features influence detection rate was also explored in this study.

Image Evaluation

Ten participants evaluated twenty luggage images, which each contained a single target threat item, on a five-point rating scale. For each image they had to rate the overall visual complexity of the luggage item, then the threat item was clearly demarcated and they had to rate their familiarity with the threat depiction and its visual conspicuity within the image. The visual complexity of the bag was explained to participants as meaning 'the degree of difficulty in providing a verbal description of an image' (Heaps & Handel, 1999). This is a multi-dimensional concept which relates to the quantity of objects, clutter, symmetry, organization and variety of colours in an image. The familiarity of a threat item, in this study, meant the degree of similarity between a participant's concept of such a threat (e.g. the X-ray image of the side view of a hand gun) and the shape of a threat item on the screen (e.g. the X-ray image of a gun as seen 'barrel–on'). The conspicuity of an object relates to object properties and its surroundings, such as brightness, colour, contrast, etc. The visual conspicuity of a threat item refers to the discrepancy between the appearance of a threat item and its local background - an obvious threat item should stand out from the immediate background.

Results

Data were analysed using Receiver Operating Characteristics methodology and the mean overall performance of the naïve participants had an accuracy measure (A_z) value of 0.74. The overall results are presented elsewhere (Liu et al, in press).

For TP decisions, the time to first enter the AOI (1033.76 ms) was shorter than that of FN decisions (1393.82 ms) and the dwell time for FN decisions (5918.19 ms) was longer than that for TP decisions (5804.53 ms). However, the differences were not significant ($F (1,188) = 1.419$, $p = .235$) and ($F (1, 198) = .020$, $p = .888$) respectively. The number of data points considered for dwell time is more than for the 'time to enter AOI' analysis as some target threats were not fixated.

Four guns were used as potential threat items in this study, two of them were presented in front (end –on) view and the other two were presented in side view. Only one decision was an error for the side view gun images compared to eight incorrect decisions for the end-on view guns. The visual angle subtended by the gun influenced the detection rate ($\chi^2 = 13.789$, df = 1, $p < .001$).

The subjective variable 'bag visual complexity' affected the time to first enter the AOI ($F (1, 18) = 5.723$, $p < .05$), this being significantly longer for a complex than a simple bag. The total dwell time on a complex bag (14.67 s) was longer than that on a simple bag (12.50s), however the difference was not significant ($F (1, 18) = 1.430$, $p = .247$). The visual complexity of bags did not influence the detection rate significantly ($F (1, 18) = .022$, $p = .882$).

The familiarity of the threat item did not influence the time to first enter the AOI ($F (1, 18) = .008$, $p = .931$) or the dwell time on the AOI ($F (1, 18) = 4.359$, $p = .051$). Familiarity significantly influenced detection rate ($F (1, 18) = 5.432$, $p < .05$). The threat items detected by eight or more observers were rated with significantly higher familiarity scores (more familiar) than those detected by seven or fewer observers (Figure 1).

The conspicuity of a threat item influenced the time to first enter its AOI ($F (1, 18) = 6.055$, $p < .05$) and the rate of dwell time on AOI of total dwell time on bag image ($F (1, 18) = 5.319$, $p < .05$). As the degree of conspicuity of the threat item increased, the time to first enter the AOI decreased and the rate of dwell time on AOI of total dwell time on image increased significantly. Threat items detected by seven or more observers were scored higher conspicuity (more conspicuous) than those detected by six or fewer observers, but the difference was not significant (F (1, 18) = .480, p = .497).

Overall, the first time to enter AOI of guns and knives was significantly longer (F (1, 188) = 11.401, p < .01) than that of IEDs (1730.73 ms vs. 778.48 ms, respectively). Total dwell time on AOI of guns and knives was shorter (3895.86 ms) than that of IEDs (7140.43 ms), and the difference was significant (F (1, 198) = 19.165, p < .01).

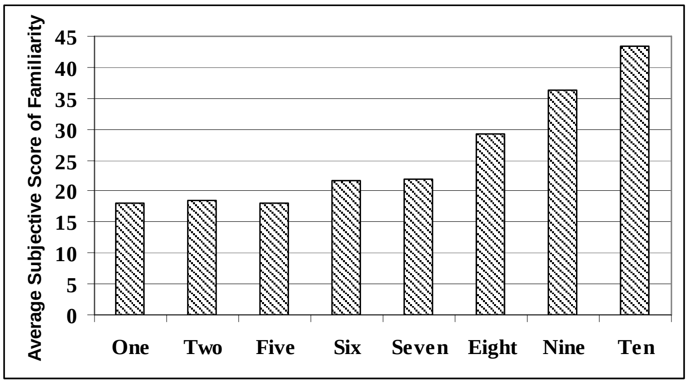

Figure 1. Number of participants detecting a threat item (e.g. two = two out of ten) as a function of the familiarity score of the threat item (a higher score represents a more familiar threat item).

Discussion

The results demonstrated that naïve individuals, after a very short familiarisation of the X-ray appearance of threats, can perform better than chance in examining luggage images for other threat items. Three subjective evaluation variables were used to explore luggage and threat item features and their influence on detection rate and visual search by naïve observers. The familiarity of threat items influenced detection rate significantly although both the visual complexity of bags and the conspicuity of threat items did not. This implies that object knowledge of threat items is very important for detection and recognition. A clear definition of a target is an effective way for improving detection performance (Kundel & La Follette, 1972) and training target materials should be maximally heterogeneous to ensure skill generalization (McCarley et al, 2004).

Schwaninger et al. (2004) found that the viewpoint, the bag complexity and superposition influenced detection performance. The present study also showed that the apparent visual size of a gun influenced detection rate significantly. Target materials employed during training should include targets presented at difficult visual angles, even when the targets can be assumed to be known by most people. Naïve observers knew more about gun and knife appearances a shown by the shorter times ('first enter AOI' and dwell) than with IEDs.

Visual complexity of the bag influenced the time to enter AOI and the conspicuity of threat items significantly influenced the time to enter AOI and the rate of dwell time on AOI of total dwell time on the bag image. This indicated that a complex background and an obscure target increased the difficulty of cognitive processing, therefore increased the time to enter target AOI and those two variables were related to each other. Threat conspicuity is related not only to targets themselves but also the background. Bag complexity contributes to threat item conspicuity and would influence the dwell time distribution on an image. Conspicuous threat items attracted attention earlier in search and had more dwell time compared to total dwell time on the image. Missed targets did not appear to attract attention for approximately 360 ms later in the time to first enter the AOI, compared to detected targets. According to most models of visual search, search begins with a global scanning stage and scrutiny is allocated to selected features. One of the possible reasons that naïve participants allocated more attention to a conspicuous target was that they lacked the object knowledge of a threat item.

Conclusions

Naïve participants were able to identify X-ray images of potential threat items, although they took a long time to do so. Not surprisingly, they were more familiar with the appearances of guns and knives than IEDs. The visual angle subtended by a gun and the familiarity of threat items influenced the detection rate significantly. The complexity of bags and the conspicuity of threat items influenced the initial attention on target threats.

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