X-ray Imagery:

enhancing the value of the pixels

*Whilst huge strides have been made in the enhancement of X-ray technology, how can we best benefit from the better imagery provided to us and use the data provided us by the X-ray monitors pixels to its best advantage? **Adrian Schwaninger** casts an eye on the relationship between operator and machine.*

Over the last few decades, significant technological prog–ress has been made in aviation security. This is especially evident in X-ray screening. Image resolution, for example, has improved substantially; this is important to detect wires of an improvised explosive device (IED).

Another important aspect is how colour information is displayed. We investigated this in a study in the year 2000 before the new X-ray equipment for hold baggage screening was installed at Zurich airport. Colour was already available in older equipment to indicate different materials. The problem with the older X-ray screening systems was that colouring was opaque, i.e. object parts were obscured by the colouring algorithm. Figure 1 illustrates the problem.

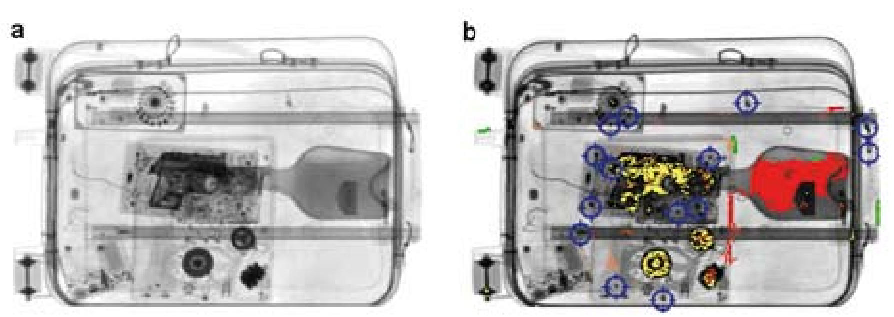


Figure 1. Opaque colouring algorithms of older X-ray imaging systems. a: greyscale image b: image with opaque colouring.

Whereas in the greyscale image the gun is clearly visible (Figure 1a), it becomes more difficult to recognise when the opaque colouring is activated (Figure 1b). In order to examine such effects, a test with 80 screeners was conducted in 2000 containing three different display conditions (for details see Schwaninger, 2005a). In condition 1, only greyscale images were shown. In condition 2, images were shown in colour only. In condition 3, images were shown in colour

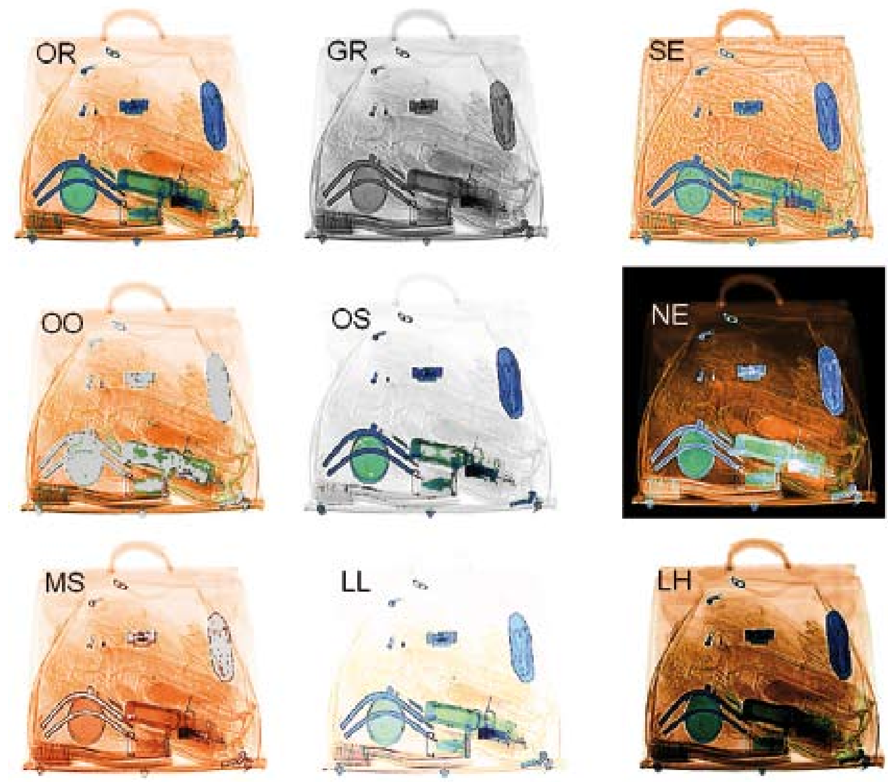


Figure 3. Different image enhancement functions available on state-of-the art X-ray screening systems. OR: original image, GR: greyscale, SE: super enhancement, OO: organic only, OS: organic stripping, NE: negative image, MS: metal stripping, LL: lum low, LH: lum high.

and then in greyscale. The third condition was the most similar one when compared to the situation at the checkpoint. There, images were shown with opaque colouring and it was possible to remove the colour by pressing a button – a feature that was in fact often used by the screeners. The results of the study are depicted in Figure 2 for weapons, dangerous goods and other threat objects.

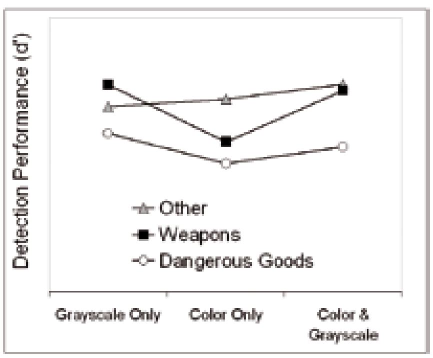


Figure 2. Results of the study on colour display conducted in 2000 at Zurich airport.

Detection of guns and dangerous goods was significantly impaired in condition 2 (colour only) as compared to the other two conditions. This effect was due to the opaque colouring algorithm, which obscured object parts. Fortunately, when images were shown in colour and then in greyscale this impairment was eliminated (condition 3). The problem of opaque colouring was definitively solved in 2002, by installing the new hold baggage screening system at Zurich airport. This system provides high resolution images with a transparent colouring algorithm similar to the images depicted in Figure 3.

Investigating the value of image "enhancement" functions

State-of-the art X-ray screening systems provide many image enhancement functions such as negative, black and white image, super enhancement, organic stripping, organic only etc. Examples are shown in Figure 3. Note that the figure contains only a subset of all the available functions; some manufacturers provide dozens of different ways to filter the X-ray image.

At least in the nineties one could often get the impression that the more image enhancement functions are available, the better a machine can be sold to customers. The term image "enhancement" reflects the marketing aspect of these functions: The more such functions are provided the more "enhancements" a customer would be able to apply. Interestingly, until recently no systematic research has been conducted to determine which functions are useful and which do actually impair detection performance. We have started three studies this year to fill this gap. Two studies are currently conducted at Zurich airport; one with cabin baggage screeners and one with hold baggage screeners. The other study is being conducted in collaboration with colleagues in the USA. First results are already available from Zurich based on 83 hold baggage screeners who participated in a test on detection of IEDs. The original image and five image enhancements were tested (greyscale, super enhancement, organic only, organic stripping and negative image).

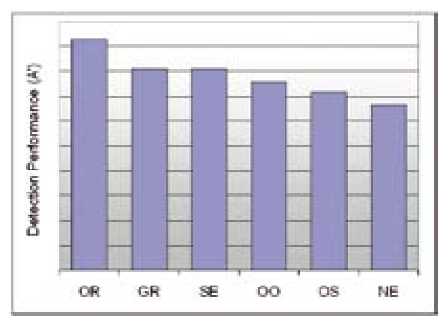


Figure 4. Results of the HBS image enhancement study conducted recently at Zurich airport. OR: Original image, GR: greyscale, SE: super enhancement, OO: organic only, OS: organic stripping, NE: negative image.

As you can see in Figure 4, IED detection performance was best when images were displayed without image enhancements. Performance decreased slightly when images were presented in greyscale or with the super-enhancement algorithm. A substantial decrease of detection by screeners was observed for organic stripping, organic only and especially for the negative image. Although in the negative X-ray image wires might be better visible, the whole image looks very different due to the colour inversion which explains the worst performance in this condition. Note that in this study, all

Right: Figure 7. Threat objects often look very different in the X-ray image than in reality. a X-ray image containing a taser weapon, b X-ray image of a bag with a self-defence gas spray.

image enhancements actually decreased performance, which is somehow ironic when considering their name. However, it should be noted that these results are based on a first study on IED detection in X-ray images of hold baggage. More detailed results of this and the other two studies on cabin baggage screening and detection of guns, IEDs, knives and other threat items will be available and published in 2006.

Pre-employment assessment and visual abilities

What we see is the result of visual processing in our brain. Since brains differ, their abilities to process the information contained in X-ray images varies. Three image-based factors challenge the detection of threat objects in X-ray images (Schwaninger, 2003b; Schwaninger, Hardmeier & Hofer, 2004, 2005). This is illustrated in Figure 5.

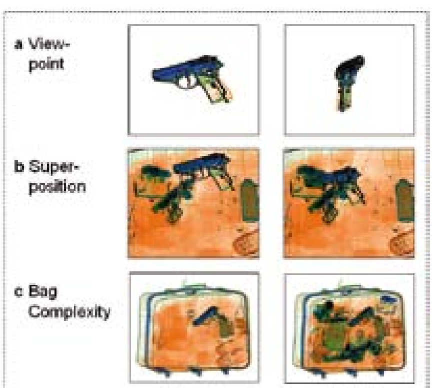


Figure 5. Image-based factors challenging the detection of threat objects in X-ray images.

Objects become more difficult to recognise if they are depicted in an unusual view (effect of viewpoint). If a threat item is superimposed by other objects, recognition can be impaired (effect of superposition). Depending on the type and number of other objects in the bag, visual attention is distracted, which can also affect detection performance (effect of bag complexity). Two years ago, we have developed computer-based tests to identify job applicants who have the necessary visual and cognitive abilities needed in X-ray screening. In addition to a colour blindness test and different cognitive tests, our computer-based pre-employment assessment system features the X-ray Object Recognition Test, which is a reliable, valid and standardized tool to measure the above mentioned abilities needed in X-ray screening (for details see Schwaninger, 2003b; Schwaninger, Hardmeier & Hofer, 2004, 2005; Hardmeier, Hofer, & Schwaninger, in press). By using these tests to select candidates prior to employment the detection performance can be increased substantially. This is illustrated in Figure 6, which shows the results of a competency assessment procedure that all screeners in Switzerland have to take periodically. Screeners, who have been selected with our new pre-employment assessment tests, have performed substantially better in the competency assessment after several months than other screeners that were selected with the older pre-employment assessment procedure. This was found for the X-ray Object Recognition Test containing guns and knives (ORT), for the X-ray Prohibited Items Test containing different kinds of prohibited items (PIT) and also for the theoretical exam on computer (TEC), containing questions on theoretical knowledge needed in X-ray screening. In all three competency tests, screeners who were selected with the new pre-employment assessment system did significantly outperform the other screeners. The results in the three tests of the competency assessment provide converging evidence for the usefulness of a scientifically based pre-employment assessment system to increase performance substantially.

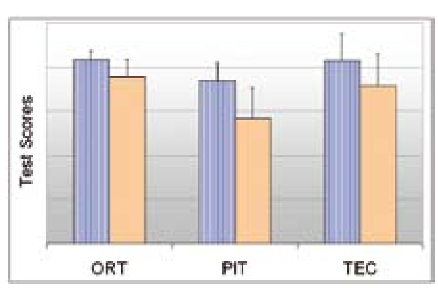


Figure 6. A scientifically-based pre-employment assessment system can increase performance in X-ray screening substantially. Screeners that were selected using the new pre-employment assessment system (blue textured bars) outperformed other screeners (orange non-textured bars) substantially in the X-ray Object Recognition Test (ORT), in the X-ray Prohibited Items Test (PIT), and in the theoretical exam on computer (TEC).

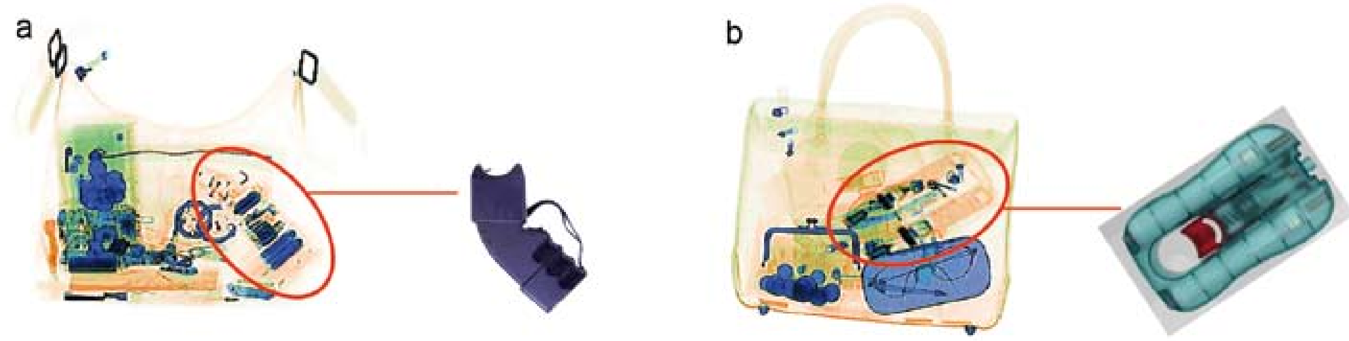
The value of the pixels has to do with the human brain

Visual information contained in the pixels of X-ray images is processed by our brain, which results in the experience of seeing something. What we look at is compared to what we have stored in visual memory based on previous experience. If threat objects in X-ray images look different to what we have learnt, they become difficult to recognise. This is especially important in X-ray screening, because many threat objects look quite different than in reality. Consider the images depicted in Figure 7. The taser weapon looks very different in the X-ray image than in reality (Figure 7a). Similarly, the self-defence gas spray in Figure 7b is a totally different pattern in reality than when displayed as X-ray image. These examples illustrate that the best image quality is of little value if the screeners who have to interpret the image do not receive appropriate training to learn which items are prohibited and what they look like in X-ray images.

How to increase detection performance substantially

In order to train new and experienced screeners to detect threat items reliably within a few seconds of image inspection, we have developed an individually adaptive training system by bringing together scientific and aviation security experts. X-ray Tutor is based on the results of scientific studies on how the human brain processes visual information to recognise objects. This knowledge, combined with sophisticated training algorithms, create the world's only, scientifically based individually adaptive training programme for X-ray image interpretation. The United States Transportation Security Administration (TSA) is using X-ray Tutor at over 400 airports across the country since spring 2004 as part of its recurrent training and professional development programme for airport security screeners. TSA has also funded the development of X-ray Tutor version 2.0. The Canadian Air Transport Security Authority (CATSA) is currently installing X-ray Tutor at all Canadian airports. X-ray Tutor is successfully used in Switzerland since 2002, at 17 airports in Germany since 2003, and in several other countries such as Australia, Belgium, Bulgaria, Korea, Latvia, New Zealand, Portugal, and The Netherlands.

A sophisticated algorithm allows virtual



placement of threat objects in X-ray images of passenger bags. This automatic algorithm of X-ray Tutor is very effective, scientifically approved and takes into account effects of viewpoint, superposition by other objects and bag complexity (Schwaninger, Hardmeier & Hofer, 2004, 2005; Schwaninger, Michel & Bolfing, in press). Due to this specialized feature, X-ray Tutor always presents screeners fresh images which constantly challenge interpretational skills. Each training session is adapted to each individual screener in order to achieve optimal training effects. Most importantly, screeners receive immediate feedback for each image containing a threat object (see Figure 7).

The effectiveness of X-ray Tutor has been proven in several scientific studies, showing that screeners become able to detect threat

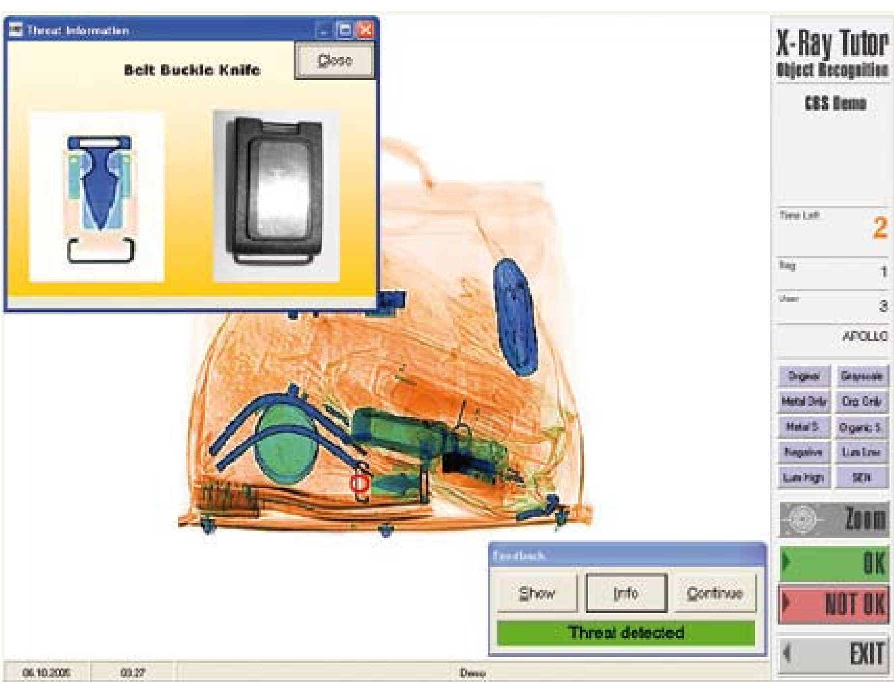


Figure 8. Interface of X-ray Tutor Version 2.0 with feedback on each threat image.

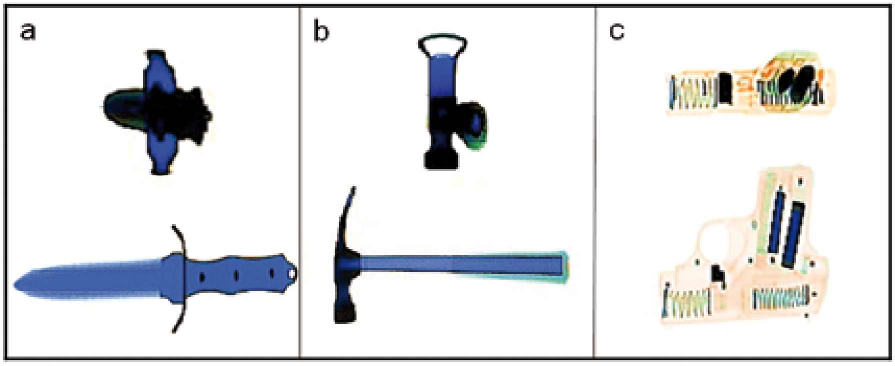


Figure 9. When depicted from an unusual viewpoint, objects can become difficult to recognise. a: dagger, b: hammer, c: soft gun. Top row: difficult view; Bottom row: easy view.

items reliably within a few seconds of image inspection. In addition to substantially increasing detection performance, training with X-ray Tutor also increases efficiency by reducing false alarms rates and response times (for details see Schwaninger, 2004b; Schwaninger & Hofer, 2004; Hofer & Schwaninger, 2004).

As explained earlier, when objects are depicted in an unusual view, they can become difficult to recognise. This is illustrated in Figure 9.

Indeed, a large number of studies in perceptual psychology and neuroscience have provided converging evidence indicating that the human brain stores objects as a collection of associated views (for recent reviews see Schwaninger, 2005a; Graf, Schwaninger, Wallraven & Bülthoff, 2002). Therefore, a large image library in which objects are depicted in different views is necessary in order to achieve reliable threat detection despite changes in viewpoint. We have developed a large multiple views library in close collaboration with airport police authorities. The current X-ray Tutor library contains more than 36,000 images and it is constantly being updated. Real explosives are used for bombs instead of simulants. Objects are captured from many different viewpoints so that threat items can be displayed in up to 72 views. A scientific algorithm determines which views are displayed and threat items are combined automatically with bag images adapted to each individual screener. The image library and algorithms allow many millions of possible threat object-to-bag combinations, adapted to each individual screener.

Comparing the value of image enhancements, selection and adaptive CBT

So how can we substantially enhance the value of the pixels in X-ray images? Until recently, many people have tried to answer this question by focusing only on imaging technology without really taking into account how the human brain processes visual information. In the last decade many different image "enhancement" features have been developed. In studies that are currently conducted by our research group in Zurich and by colleagues in the USA it is becoming clear that many image "enhancement" features do in fact impair the detection of threat objects instead of enhancing X-ray images. In fact, the real value of the pixels is rather to be found in the human brain. As mentioned above, you can only recognise an object if it is similar to what is stored in your visual memory. This is the reason why specialized individually adaptive CBT is such a powerful tool for increasing detection performance (Schwaninger, 2004b; Schwaninger & Hofer, 2004). In addition, using scientifically based methods for selecting screeners in pre-employment assessment can also lead to increases in performance. Figure 10 shows a comparison of the relative performance increases that can be achieved with adaptive CBT (X-ray Tutor) and a scientifically based pre-employment assessment system as it is used in Zurich since 2004. To illustrate the negative impact image enhancement features can have, the bars on the right show the difference between the best image (original) and the worst image enhancement (negative image) of the above mentioned image enhancement study on detection of IEDs conducted in Zurich recently.

In summary, the results of scientific studies conducted in recent years show how important it is that knowledge about how the human brain processes visual information is taken into account when developing technological systems. An investment into modern equipment needs to be complemented with investments into human factors. The most expensive machine with the fanciest features is of little value if it is not adapted to the humans who operate it and if they are not selected and trained appropriately.

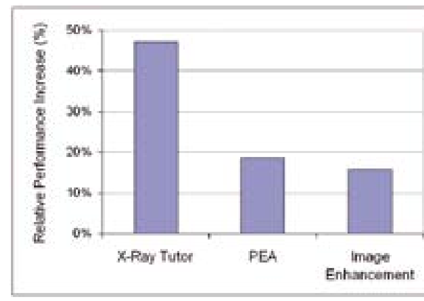


Figure 10. Relative performance increase that can be achieved with adaptive CBT (X-ray Tutor), scientifically-based pre-employment assessment (PEA) and by using the best image instead of the worst image enhancement function.

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(NOTE: All articles can be downloaded at www.psychologie.unizh.ch/vicoreg)

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