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Do multi-view X-ray systems improve X-ray image interpretation in airport security screening?

Abstract

X-ray screening of passenger bags is one of the core elements in aviation security in order to prevent terrorist attacks. Large investments have been made into new technologies, for example in multi-view X-ray systems. Because of several X-rays, multi-view systems provide more than one X-ray image of the same passenger bag and hence present the security screener multiple perspectives of that bag. In this study, we evaluated the benefit of multi-view X-ray systems compared with state-of-the-art single-view X-ray systems. Single- and multi-view X-ray images of passenger bags were presented to 32 novices who had to decide if the bag contained a prohibited item or not. The results show that multi-view X-ray systems lead to a higher detection performance of prohibited items in difficult conditions, such as when it is rotated in a non-canonical manner or superimposed by other objects. Additionally, the results indicate an increase of the reaction time for performing the screener's task with multi-view in comparison with single-view X-ray systems. A specific training for airport's security screeners might increase the advantages and reduce the disadvantages of multi-view X-ray systems.

Keywords: aviation security, display technologies, human machine interaction, object recognition, visual psychophysics, X-ray imaging

Résumé

La radiographie des colis de voyage au contrôle de sécurité est un élément principal de la sécurité de l'aviation pour la prévention des attaques terroristes. Des grands investissements pour des nouvelles technologies ont été réalisés, entre autre pour la radiographie Multi-View. Les appareils de radiographie Multi-View produisent plusieurs images d'un colis en utilisant plusieurs rayons X. Cette étude analyse les avantages des systèmes Multi-View par rapport à des appareils usuels utilisés aujourd'hui. Comme étude, des radiographies des colis en Multi-View et en Single-View ont été présenté aux 32 laïques. Pour chaque image, les participants devaient décider si l'image contenait un objet prohibé. Les résultats indiquent que la performance de la détection est meilleure avec la radiographie Multi-View, si l'objet prohibé est tourné d'une manière non-canonique ou est éclipsé par un autre objet. Le temps de réaction pour accomplir l'exercice est plus élevé pour les images Multi-View. Un training spécifique pour les agents du contrôle de sécurité est une possibilité pour augmenter les avantages et réduire les désavantages de la radiographie Multi-View.

Zusammenfassung

In der Luftfahrtsicherheit ist das Röntgen von Gepäckstücken bei der Sicherheitskontrolle eines der Hauptelemente zur Prävention terroristischer Anschläge. Es wurden große Investitionen in neue Technologien getätigt, wie zum Beispiel in Multi-View Röntgensysteme. Dabei handelt es sich um Röntgengeräte, die aufgrund multipler Röntgenstrahlen mehrere Röntgenbilder von einem Gepäckstück erstellen, sodass die Mitarbeitenden der Sicherheitskontrolle von diesem Gepäckstück mehrere Ansichten betrachten können.

Die Erkennung verbotener Gegenstände in Röntgenbildern von Gepäckstücken hängt einerseits von wissensbasierten, andererseits von bildbasierten Faktoren ab (Hardmeier et al. 2005; Schwaninger et al. 2004). Erstere beziehen sich auf das Wissen, welche Gegenstände verboten sind und wie diese im Röntgenbild aussehen. Bildbasierte Faktoren hingegen haben einen Einfluss auf die Schwierigkeit eines Bildes. Schwaninger (2003) beschrieb drei bildbasierte Faktoren: Rotation des verbotenen Gegenstands, Verdeckung des verbotenen Gegenstands durch andere Objekte, und die Transparenz der des Gepäckstücks.

In der vorliegenden Studie untersuchten wir den Nutzen der Multi-View Systeme im Vergleich zu den heutzutage üblichen Single-View Röntgensystemen. Dazu führten wir ein Experiment durch, um den Einfluss multipler Ansichten auf die Erkennungsleistung sowie die Reaktionszeit zu messen. Damit der Einfluss wissensbasierter Faktoren ausgeschlossen werden konnte, führten wir das Experiment mit 32 Laien durch und präsentierten nur Schusswaffen und Messer, da deren Erscheinungsbild relativ alltäglich ist. Unsere Hypothese lautete, dass bei der Verwendung von Multi-View Systemen die Erkennungsleistung vor allem bei schwierigen Bedingungen steigt, das heißt wenn der verbotene Ge-

genstand rotiert ist oder stark durch andere Objekte verdeckt wird, da eine zweite Ansicht des Gepäckstücks den Einfluss dieser beiden bildbasierten Faktoren vermindern sollte. Darüber hinaus nahmen wir an, dass die Reaktionszeiten bei Multi-View Bildern länger sind als bei Single-View Bildern, da die visuelle Suche für multiple Ansichten des Gepäckstücks mehr Zeit in Anspruch nimmt als für nur eine Ansicht.

Für unser Experiment konstruierten wir einen aus Röntgenbildern von Gepäckstücken bestehenden Test. Die Hälfte der insgesamt 128 Gepäckstücke hatte eine niedrige, die andere Hälfte eine hohe Transparenz. Jedes Gepäckstück wurde zweimal verwendet, einmal in Kombination mit einem verbotenen Gegenstand (Schusswaffen und Messer) und einmal ohne. Darüber hinaus variierten wir die Rotation und Verdeckung des verbotenen Gegenstands. Alle Bilder wurden jeweils einmal als Single-View und einmal als Multi-View Trial präsentiert. Insgesamt wurden den Teilnehmenden 512 Bilder präsentiert: 16 (verbotene Gegenstände) * 2^3 (bildbasierte Faktoren Rotation, Verdeckung, Transparenz) * 2 (Single- bzw. Multi-View) * 2 (Gepäckstück mit/ohne verbotenen Gegenstand). Bei jedem Bild mussten die Teilnehmenden entscheiden, ob das Gepäckstück einen verbotenen Gegenstand enthielt oder nicht.

Die Resultate bestätigten unsere Hypothesen. Wir konnten zeigen, dass der verbotene Gegenstand eher mit einem Multi-View Röntgensystem als mit einem herkömmlichen System entdeckt wird, falls er auf eine non-kanonische Weise rotiert oder von anderen im Gepäckstück enthaltenen Objekten verdeckt wird. Darüber hinaus weisen die Ergebnisse darauf hin, dass die Reaktionszeiten für das Lösen der Aufgabe bei Multi-View Röntgenbildern länger als diejenigen bei Single-View Röntgenbildern sind. Ein spezifisches Training für die Mitarbeitenden der Sicherheitskontrolle könnte die Vorteile der Multi-View Röntgensysteme mehren und die Nachteile reduzieren.

Praktische Relevanz

Die zunehmende globale Mobilität wie auch verschärfte Sicherheitsbestimmungen tragen wesentlich zur Erhöhung der Belastung des Personals bei Sicherheitskontrollen am Flughafen bei. Neue Röntgengeräte ermöglichen eine Mehrfachansicht der zu untersuchenden Gepäckstücke, um dadurch die Erkennung gefährlicher Gegenstände zu erleichtern. Die Erkennungsleistung und somit die Beanspruchung hängt von der Anzahl der Ansichten ab. Eine Belastungsminderung lässt sich durch Trainieren der Wiedererkennungsfähigkeit für gefährliche Gegenstände erreichen.

1 Introduction

The increasing threat of terrorist attacks in recent years has led to large investments into technological enhancements in aviation security. One main focus continues to be the improvement of the process of X-ray screening of passenger bags to prevent forbidden objects getting past the security checkpoint.

Some airports have started using technologies of the newest generation for the process of cabin baggage screening, such as multi-view X-ray systems. Certain multi-view X-ray systems even provide automated detection of explosives, leading to a substantial improvement of security. However, for the detection of other types of prohibited items, airports still rely on human operators (airport security screeners) who visually inspect X-ray images.

The task of threat object detection depends on knowledge-based and image-based factors (Hardmeier et al. 2005; Schwaninger et al. 2004). Knowledge-based factors refer to knowing which items are prohibited and what they look like in X-ray images of passenger bags. Some objects look quite different in X-ray images than in reality, for example an electric shock device, which is difficult to differentiate from ordinary objects (see Figure 1). Others, such as Improvised Explosive Devices (IED), are rarely seen in everyday life as well as at the security checkpoint and are, therefore, difficult to recognize without the appropriate training.

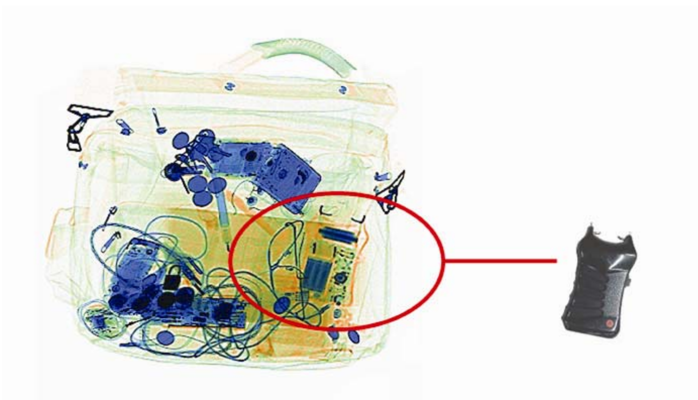

Figure 1: Illustration of the impact of knowledge-based factors. Some forbidden objects such as the electric shock device shown above look quite different in X-ray images than in reality.

Furthermore, image-based factors play an important role in threat object detection. These can be attributed to the visual abilities of a person, that is, how he or she copes with image difficulty. Schwaninger (2003) described three image-based factors: rotation, superposition, and bag transparency (Figure 2).

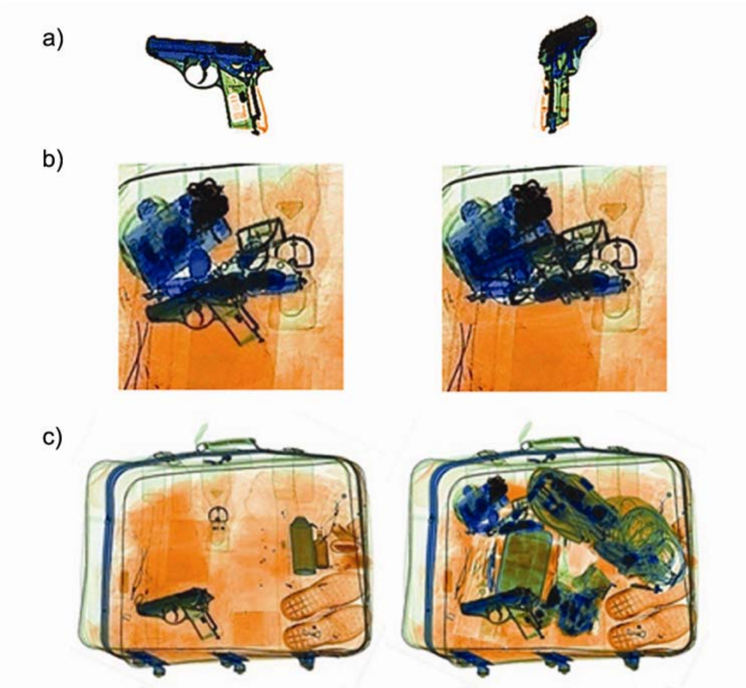

Figure 2: Image-based factors with an impact on threat detection performance: (a) easy and difficult rotation, (b) low and high superposition, and (c) low and high bag transparency.

The fact that object recognition often yields strong effects of viewpoint caused by the rotation of an object (e.g. Bülthoff & Edelman 1992; Graf et al. 2002; Tarr & Bülthoff 1995, Tarr & Bülthoff 1998), is essential for X-ray image interpretation. In general, X-ray images of forbidden objects are difficult to recognize when depicted from an unusual viewpoint and when diagnostic features are not visible.

Another important factor contributing to image difficulty is the superposition of the threat object by other objects in a bag. The effect of superposition refers to the impairment of figure-ground segregation. If a threat object, such as a knife, is superimposed by high density material, it becomes more difficult to recognize the characteristic shape of the object.

Furthermore, the transparency of a bag, determined by the number and type of objects in the bag, has a significant influence on the detection performance. Recently, the effects of the image-based factors rotation, superposition and bag transparency have been replicated, and statistical algorithms for estimating image difficulty have been developed (Schwaninger et al. 2007b).

Besides coping with knowledge-based and image-based factors, the screener has to detect a threat object in a limited amount of time. During rush hour at the security checkpoint, screeners often have only a few seconds to visually inspect the X-ray images of passenger bags.

There is evidence that perceptual training can help to improve the ability to segment objects from cluttered visual scenes (e.g. Brady & Kersten 2003; Kourtzi et al. 2005; Kovacs et al. 1999; Li & Gilbert 2002; Yi et al. 2006). Furthermore, it has been shown that a specific X-ray screening training increases the X-ray image interpretation competency and decreases reaction times (Koller et al. 2007, Koller et al. 2008; McCarley et al. 2004; Michel et al. 2007; Schwaninger et al. 2007a). Such a computer-based object recognition training affects mainly knowledge-based factors and the detection of rotated objects (Schwaninger et al. in press). Through training, airport's security screeners learn which objects are prohibited and how they appear in X-ray images. The screeners also store different and often unfamiliar views of the objects in visual memory (Michel et al. 2007).

Effects of image-based factors might also be diminished by recent technological improvements. Multi-view X-ray systems produce two or more images of one object taken from different viewpoints due to several X-rays. In airport security screening this means that the decision of the screener, if a passenger bag is OK or not, is supported by multiple images of the same bag. Threat objects that are rotated in a non-canonical manner or superimposed by other objects in the bag might be recognized easier when a second, e.g. 90 degree rotated view, is available. Assuming that visual search needs more time for multiple images than for a single image, reaction times are probably longer for multi-view than for single-view X-ray systems.

In this study, we conducted an experiment in order to investigate what impact multiple views have on the detection performance as well as on the reaction time of a screening person. In order to eliminate the influence of knowledge-based factors, we conducted the experiment with novices who had no prior expertise in X-ray screening, and we presented only threat objects, whose appearance is relatively common in everyday life, such as guns and knives. We will examine the impact of the X-ray system on the introduced image-based factors rotation and superposition, as well as on the reaction time.

Our hypothesis is that with multi-view X-ray systems, the detection performance increases especially for difficult conditions, i.e. a difficult rotation or a high superposition of the threat item, based on the assumption that a second view might eliminate or at least reduce the negative influence of the introduced image-based factors. Additionally, reaction times probably increase for multi-view X-ray systems in comparison with single-view X-ray systems because visual search needs more time for multiple images, as mentioned above.

2 Method

2.1 Participants

Thirty-two undergraduate students from the University of Zurich volunteered to participate in this study; 20 females and 12 males with age ranging from 19 to 50 years (*M* = 26.69 years, *SD* = 6.35 years). All participants reported normal or corrected-to-normal vision. They were all naive with regard to the hypotheses under investigation.

2.2 Material

For our experiment we constructed a test consisting of X-ray images of passenger bags by using a multi-view X-ray system. The approximate directions of the two X-ray beams are illustrated schematically in Figure 3.

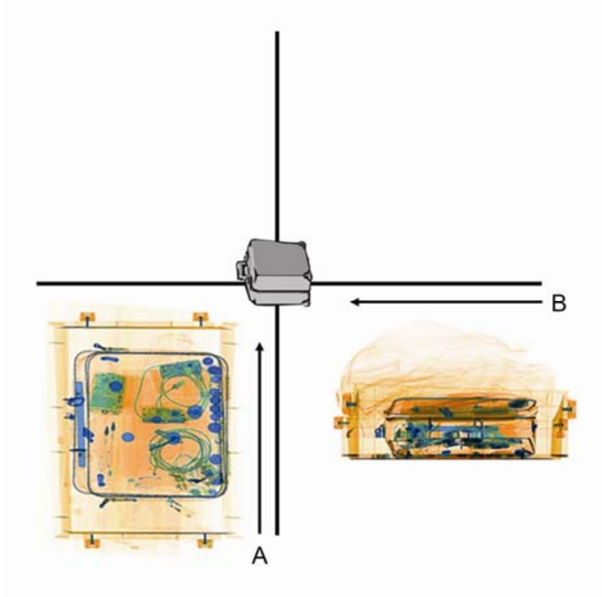

Figure 3: Schematic illustration of the approximate directions of the two X-ray beams A and B.

One half of the total of 128 bags in our experiment had a low, and the other half a high bag transparency. We calculated the level of bag transparency using the formula for transparency, which reflects the extent to which X-rays are able to penetrate objects in a bag, as described by Schwaninger et al. (2007b):

$$TR = \frac{\sum_{x,y}(I_N(x,y) < threshold)}{\sum_{x,y}(I_N(x,y) < 255)}$$

$I_N(x, y)$ denotes the pixel intensities, whereas threshold is the pixel intensity threshold beneath which the pixels are counted.

All of the bags were used twice, once combined with a prohibited item, and once without any threat object. The threat objects have been captured by experts of Zurich State Police, Airport division. Because we tested novices who were not trained in recognizing unfamiliar objects like IED, we only used eight guns and eight knives to eliminate effects of knowledge-based factors. Each threat item was presented in two different rotations. The easy rotation shows the object from a canonical perspective (Palmer et al. 1981) as judged by two security experts who captured the stimuli. The difficult rotation shows the threat item 85 degree rotated horizontally or vertically relative to the canonical view.

Every threat item was combined with a bag in a manner that the degree of superposition by other objects was low, and with another bag in a manner that the degree of superposition by other objects was high. For this purpose we used the formula for superposition as described by Schwaninger et al. (2007b):

$$SP = \sqrt{\sum_{x,y} (I_{SN}(x,y) - I_N(x,y))^2}$$

The function computes the difference between the pixel intensity values of the bag image with the threat object ($I_{SN}(x, y)$) minus the pixel intensities of the corresponding harmless bag ($I_N(x, y)$).

Every image was once presented as single-view and once as multi-view trial. The single-view condition consisted of one view (see Figure 2, X-ray A), i.e. one image was shown, the multi-view condition consisted of two views (see Figure 2, X-rays A and B), i.e. two images were presented at once on the same screen. The size of the bag images was consistent regardless of the condition. As shown in Figure 4b, the first view (left side) of the multi-view trial was identical with the corresponding single-view trial, whereas the second view (right side) was an image of the same bag from another angle.

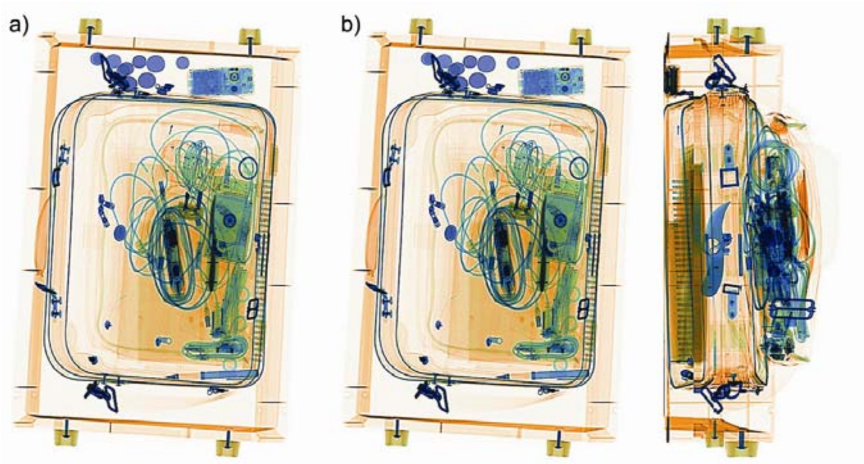

Figure 4: (a) A single-view trial containing a knife in a difficult rotation and high superposition and (b) the corresponding multi-view trial. In the second view of the multi-view trial, the rotation of the threat object is easy and the superposition low.

The variation of the image-based factors rotation, superposition, and bag transparency resulted in eight variations for the single-view condition, and, therefore, also for the first view of the multi-view condition. In the second view, we varied the factors rotation and superposition again, resulting in another four variations for the second view: easy rotation and low superposition, easy rotation and high superposition, difficult rotation and low superposition, and difficult rotation combined with high superposition.

These four variations of the second view have been balanced throughout four groups of participants (cp. Table 1). Overall, 512 trials were presented: 16 (threat objects) * 2^3 (image-based factors rotation, superposition, bag transparency) * 2 (single-/multi-view X-ray system) * 2 (bag with/without threat item).

Table 1.

Multi-view variations of bags containing a threat item

Bag and its transparency	First view	Second view g1	g2	g3	g4
low					
1	t1r1s1	t1r1s1	t1r2s1	t1r1s2	t1r2s2
2	t2r1s1	t2r2s1	t2r1s2	t2r2s2	t2r1s1
3	t3r1s1	t3r1s2	t3r2s2	t3r1s1	t3r2s1
4	t4r1s1	t4r2s2	t4r1s1	t4r2s1	t4r1s2
…	…	…	…	…	…
high					
…	…	…	…	…	…
128	t16r2s2	t16r2s2	t16r1s1	t16r2s1	t16r1s2

Note. Each multi-view pair was combined once with low, and once with high bag transparency. g = participant group (1-4), t = threat item (1-16), r = rotation (1: easy, 2: difficult), s = superposition (1: low, 2: high).

2.3 Procedure

All participants performed the test in a training classroom at Zurich Airport, where we were able to maintain standardized conditions regarding lighting, computer and monitor settings.

First, we tested the color perception of the participants using Ishihara's test of colour-blindness with 14 plates (2003). All participants scored 100% correct.

Within the introduction, participants were shown 16 X-ray images of guns and knives which were not used in the experiment in order for them to get an idea of what such weapons look like in X-ray images. After 4 practice trials, participants had to accomplish the 512 trials (single-view and multi-view mixed). They had to decide whether the bag presented was OK (contains no threat item) or NOT OK (contains a threat item) by clicking the respective button on the screen. Additionally, participants were asked to indicate how confident they were in their decision by clicking on a rating scale (non-visible 100 point) on the screen.

The 512 trials have been subdivided into four blocks and participants were allowed to take a short break after completing each block. Trials were randomized within each block and block order was counterbalanced across two groups of participants. Completing the experiment took about 60-90 minutes.

3 Results

We calculated the detection performance of the participants using the signal detection measure *d'*, which is derived from hit and false-alarm rates (Green & Swets 1966). While the hit rate refers to the proportion of all images containing a prohibited item that have been judged as NOT OK, the false-alarm rate refers to the proportion of NOT OK judgments for harmless bags. The advantage of *d'* compared to other sensitivity measures is the fact that it is invariant when factors other than sensitivity change (Macmillan & Creelman 2005). For calculating *d'* we used the following formula:

$$d' = z(H) - z(FA)$$

where H is the hit rate, *FA* the false alarm rate and *z* refers to the z transformation.

Across all conditions, there was no significant difference in *d'* between single-view and multi-view X-ray system, $t(31) = -0.53$, $p = .30$, $d = 0.04$.

Before we examined the impact of the X-ray system on the image-based factors rotation and superposition, we analyzed the data obtained in the single-view condition to verify the existence of the image-based factors rotation and superposition as proposed by Schwaninger (2003). For this purpose, we conducted a two-way analysis of variance (ANOVA) for repeated measures using *d'* scores with the within-participant factors rotation and superposition. It revealed large main effects of rotation, $F(1, 31) = 87.17$, $p < .001$, $\eta^2 = .74$, and superposition, $F(1, 31) = 157.72$, $p < .001$, $\eta^2 = .84$. There was also a large interaction of rotation and superposition, $F(1, 31) = 31.52$, $p < .001$, $\eta^2 = .50$. Figure 5 shows the effects of the image-based factors for the single-view condition. Remember that the easy rotation corresponds to a canonical view, and the difficult rotation to an 85 degree rotated view of the threat object around the vertical or horizontal axis. Superposition indicates how much the threat object is superimposed by other objects in the bag.

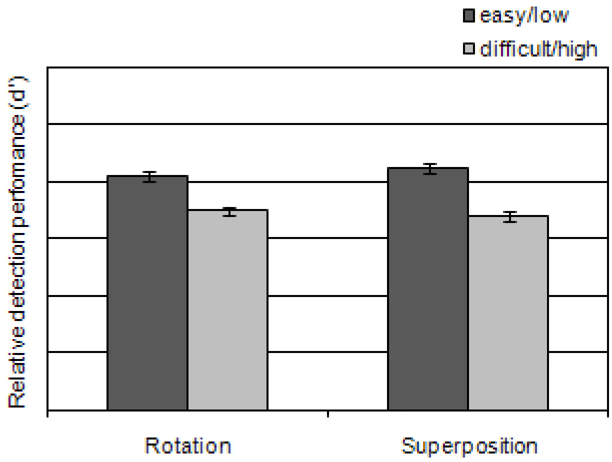

Figure 5: Effects of the image-based factors rotation and superposition for the single-view condition. Error bars represent standard errors of the mean (SEM). Note that absolute performance values are not reported due to security reasons. However, in order to provide scientifically meaningful results, effect sizes are reported throughout the paper.

As a next step, we compared the detection performance in difficult single-view conditions with the detection performance in the corresponding difficult-easy multi-view conditions, when the first view shows the difficult single-view condition and the second view the according easy condition, i.e. the threat object was presented in a canonical rotation or, respectively, with a low superposition (this is actually the case in Figure 4). An ANOVA for repeated measures with the two within-participants factors display condition (single-view, multi-view) and image-based factor (rotation, superposition) revealed a large main effect of the display condition $F(1, 31) = 25.03$, $p < .001$, with an effect size of $\eta^2 = .45$, but not for the image-based factors $F(1, 31) = 0.24$, $p = .63$, $\eta^2 = .01$. The interaction for display condition and image-based factor was also not significant $F(1, 31) = 0.34$, $p = .56$, $\eta^2 = .01$. The pairwise comparisons revealed a significant increase of the detection performance for the multi-view condition, once for rotation, $t(31) = -3.46$, $p < .001$, with an effect size of $d = 0.27$, and once for superposition $t(31) = -3.99$, $p < .001$, $d = 0.74$, as shown in Figure 7. According to Cohen (1988), the effect sizes are small (rotation) and medium (superposition).

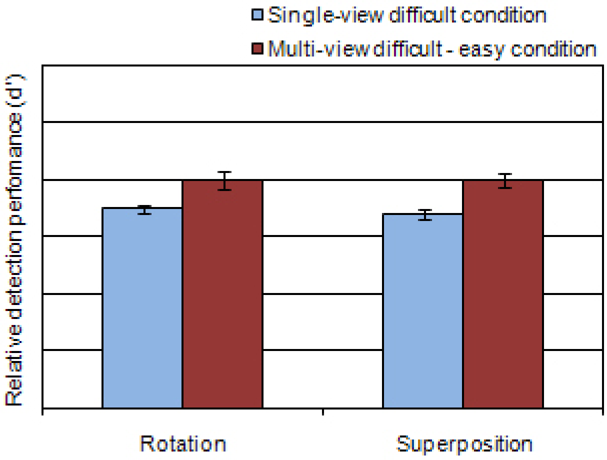

Figure 6: Effects of the display condition on the image-based factors rotation and superposition. Single-view difficult condition means a difficult rotation or a high superposition. In the difficult-easy multi-view condition, the first view was the same as in the difficult single-view condition, and the second view showed the threat object canonically rotated or with low superposition. Error bars represent standard errors of the mean (SEM). Note that absolute performance values are not reported due to security reasons.

The increase of detection performance for the difficult-easy multi-view condition in comparison with the difficult single-view condition should also be reflected by a higher average level of confidence ratings. Therefore, we conducted an ANOVA for repeated measures using the mean value of confidence rating with the two within-participants factors display condition (single-view, multi-view) and image-based factor (rotation, superposition). We found a large main effect of the display condition, $F(1, 31) = 18.03$, $p < .001$, $\eta^2 = .37$, but not for the image-based factors $F(1, 31) = 0.78$, $p = .38$, $\eta^2 = .03$. The interaction for display condition and image-based factor was also not significant $F(1, 31) = 0.34$, $p = .56$, $\eta^2 = .01$. Pairwise comparisons disclosed a significant gain of confidence, both for rotation: $t(31) = -3.51$, $p < .001$, $d = 0.39$, as well as for superposition, $t(31) = -3.40$, $p < .001$, $d = 0.44$, see also Figure 8.

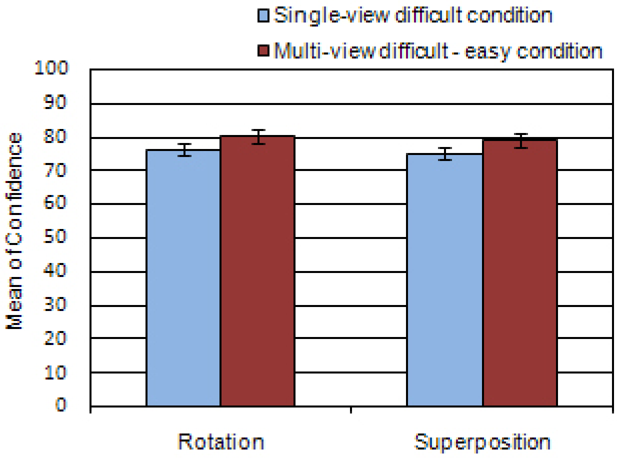

Figure 7: Effect of the display condition on the confidence ratings. Error bars represent standard errors of the mean (SEM).

Furthermore, a t-test confirmed the hypothesis that reaction times increase for the multi-view display condition in comparison with the single-view display condition, $t(31) = -12.49$, $p < .001$, $d = 0.48$, see also Figure 9.

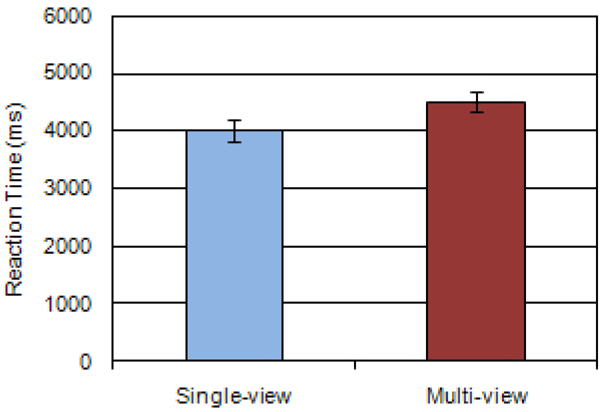

Figure 8: Effect of the display condition on the reaction time. Error bars represent standard errors of the mean (SEM).

4 Discussion

In this study, we conducted an experiment to investigate the impact of multiple views, provided by multi-view X-ray systems, on the threat object detection performance of novices. An analysis of the data pooled across all conditions revealed that there are no significant differences between the detection performance measured in *d'* for single-view and multi-view X-ray systems.

We hypothesized that the use of multi-view X-ray techniques might help especially in difficult conditions, if the threat object contained in a bag is in a difficult rotation or highly superimposed by other objects. In order to confirm this hypothesis, we first had to analyze the single-view data, to see whether we were able to replicate the effects of rotation and superposition as proposed by Schwaninger (2003). There were large main effects of rotation and superposition, and also an interaction of the two image-based factors. These results show that detection performance decreases for difficult single-view conditions.

According to our hypothesis, the threat object detection performance for the difficult conditions described above should increase, if the screening person is supported by a second view showing the threat object in an easy rotation or with a low superposition. The results of our experiment confirm this hypothesis. Moreover, the increase of detection performance with the multi-view X-ray system for difficult conditions is also reflected by a significant increase of the confidence indicated by ratings.

A probable explanation for the fact that detection performance does not increase in general for the multi-view X-ray system, but only for difficult-easy multi-view conditions might be that only in this condition the information contained in the second view is novel and helpful. In contrast, two difficult or two easy views are redundant.

Comparing the effect sizes indicates that the X-ray system has mainly an impact on superposition with a medium effect size. Whereas X-ray screening training has large effects on the detection of difficult rotated objects (Koller et al. 2008; Michel et al. 2007), Schwaninger et al. (in press) found no interaction of training and superposition. Even though our experiment revealed an effect of the X-ray system on rotation, the key benefit of multi-view X-ray systems rather seems to be the support of airport's security screeners to cope with the challenges imposed by superposition.

Furthermore, the hypothesis that reaction times increase in the multi-view condition, is confirmed, although it is only a small effect. The prolonged reaction times might be explained by the additional time needed for the visual search through two images instead of one.

In this study, we demonstrated that multi-view X-ray systems can support airport's security screeners in challenging situations, i.e. when objects in a passenger bag are difficult to recognize due to rotation or superposition. There is also a negative side-effect resulting from the multiple views: the prolonged reaction times. Previous research has shown that reaction times decrease after a certain amount of X-ray screening training (Michel et al. 2007; Schwaninger et al., 2007a).

Therefore, an adaptive computer-based training for multi-view X-ray systems which provides a realistic learning environment might be a way to tap the full potential of this novel technology.

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