

# The Influence of Age and Gender on Detection Performance and the Response Bias in X-ray Screening

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**Abstract—** X-ray screening is an essential component of airport security. In this study we investigated influence of age and gender on detection performance (sensitivity) and response bias in x-ray screening. Airport security screeners were tested with the Object Recognition Test (ORT). The ORT consists of x-ray images of passenger bags that contain guns and knives in different views with different superposition and complexity levels. The results show that age and detection performance (sensitivity measured using A') correlate negatively. Moreover, analysis of response bias (criterion measure B'') showed that women tended to be more risk averse than men. On average, women had higher hit rates but also higher false alarm rates. However, the detection performance (sensitivity) was similar between man and women. Only a small difference was found for one screener group (CBS) favoring males, whereas for the other group (HBS) no gender difference was found regarding detection performance.

**Index Terms—**airport security, x-ray screening, age, gender differences, detection performance, sensitivity, response bias

## I. INTRODUCTION

THE relevance of security procedures has strongly increased in recent years. Aviation security has become extremely important since September 11, 2001. X-ray screening is an important technology in this field and it has improved substantially to match the increased security requirements. But the technical equipment is only one aspect of security procedures. The humans who operate the x-ray screening systems take the final decision whether a passenger bag is ok or whether there is a forbidden object in it. X-ray screening is a challenging and responsible task and screeners should be carefully selected and well trained for it. It is therefore important to identify the variables that have an influence on the detection ability of screeners. For this purpose it is important to understand the underlying cognitive processes that are involved in x-ray screening.

X-ray baggage screening is a visual cognition task that

consists of several processes. A screener who looks at an x-ray image of a bag processes different objects using visual search. Whether an object is recognized as a prohibited item or not depends on image-based factors [1] such as superposition (whether the object is superimposed by other objects), rotation (how much the object is rotated) or bag complexity (whether there are many objects in the bag). Interestingly, there are large differences between people in terms of their ability to cope with these image-based factors [2]. Different models on object recognition have been proposed (for reviews see for example [3]). However, most of them agree with the following basic representational and procedural assumptions. Depending on the inspected area, an input representation is formed which is compared to what is stored in visual memory. A screener needs to be familiar with the forbidden objects in order to have developed visual memory representations of them. Most people might have a memory representation of a gun whereas they would not recognise other forbidden objects easily because they rarely see them in everyday life (e.g., an electric shock device) or because the items look quite different in an x-ray image such as for example a teaser weapon. The input representation is compared to visual memory representations which could involve mental transformations such as mental rotation. Depending on the perceived similarity of the two representations a decision is made about whether the object is harmless or forbidden and therefore whether the bag is ok or not. The x-ray screening task involves a number of cognitive abilities: visual-spatial abilities (figure-ground segregation, mental rotation), working memory capacity as well as specific knowledge about what x-ray images of prohibited items look like.

However, while the performance in x-ray screening is depending on visual abilities, the decisions that are made are also influenced by other various factors such as probability of a target stimulus, payoffs or motivation. For instance, when there is a long waiting line before a checkpoint at the airport, screeners are perhaps more likely to accept a bag as ok even though they would perhaps have it hand-searched would there be no waiting line. According to signal detection theory [4] these factors affect the subjective response bias but not detection performance in terms of sensitivity. The latter depends largely on training, e.g., [5]. In this study, we investigated whether age and gender affect response bias and

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detection performance in terms of sensitivity in x-ray screening.

#### A. Aging and Cognition

There is evidence that many aspects of cognition show a decline with aging (for a review see [6]). Some of the domains that could be relevant in x-ray screening and are associated with age-related deficits are: working memory [7], attention [8], perception [9], [10] and visual cognition [11].

1) *Memory & Attention*: One of the functions that are especially important in cognitive tasks such as x-ray screening is working memory. It is described as the central executive that processes information at a conscious level [12]. Working memory has been associated with age-related declines in various studies, e.g., [13].

Attention is also essential in x-ray baggage screening. Screeners have to be constantly vigilant which requires sustained attention (i.e. maintenance of attention across time). The relationship between age and sustained attention is not clear. For some tasks an age-related difference has been found, for others not [8].

2) *Perception & Spatial cognition*: There is evidence that declines in perception occur with aging. Age-related changes of eye structures lead to decreases in sharpness, contrast and brightness of visual stimuli [9]. The age-related loss of photoreceptors leads to a deficit of colour sensitivity [10]. The smaller number of receptors also influences visual processing in the periphery.

Several studies showed that younger subjects obtained higher scores in mental image rotation tasks than older subjects, e.g., [14]. There is evidence that endogenous sex hormones influence spatial cognition. Androgen levels change across the lifespan. In males testosterone levels for example decline with aging [15]. Some researchers report beneficial effects of androgen supplementation on spatial cognition in elderly people [16]. However, other studies do not provide any evidence for a beneficial effect of higher androgen levels [17].

#### B. Gender differences in spatial cognition

Research on gender differences suggests that men and women differ on cognitive tasks (for a review see [18]). The largest gender difference was found for spatial tasks with males performing better than females [14], [19], [20]. Men especially excel on mental rotation, the ability to rotate a two- or three-dimensional object [21]. Women, on the contrary perform better on perceptual speed [19].

There are different approaches to explain gender differences in spatial ability tasks: Hormonal influence [19], [22] socialization factors [21], evolutionary theories [23] and use of different strategies. In the following we discuss some of these theories.

1) *Hormonal influence*: Several researchers found a connection between hormones and spatial performance, e.g., [16], [22], [24]. Different levels of androgens seem to influence the organization of brain in early development and therefore affect certain cognitive abilities in adulthood.

Activational fluctuations in the androgen level have an influence as well [19]. A nonlinear relationship between spatial ability and testosterone has been found. There is obviously an optimal level of testosterone that leads to best performance in spatial tasks. This level is in the low male range, which means that for women high levels of testosterone result in a better performance whereas for men lower levels seem to be more beneficial [16].

2) *Evolutionary theories*: There is a large number of evolutionary theories explaining gender differences in spatial cognition [25]. Most of them refer to a former greater space use of males than females as a cause for the development of better spatial abilities [19]. However, only few of these hypotheses are supported by data. The range size is the most plausible hypothesis. It proposes that males had to cover a larger area to maximize their reproduction and therefore developed better spatial abilities [25].

3) *Socialization factors*: Socialization factors also play a role in cognitive abilities. It can be assumed that predisposition and social influence interact with each other. Even though there might be a biological predisposition for certain abilities, socialization influences to what extent we use our potential [21].

#### C. Relevance to x-ray screening

The first research question is whether age has an influence on x-ray screening. As several studies have shown, aging leads to cognitive declines in a number of domains. As x-ray screening is a demanding cognitive task we therefore expect a negative relationship between age and x-ray screening performance. It is imaginable though that older screeners might be able to compensate for their deficits by using their domain knowledge.

The second research questions examines if there is a gender difference in x-ray screening. Spatial abilities seem to be rather important in x-ray screening and we therefore could assume that males might outperform females. However, as x-ray screening involves different cognitive processes and spatial cognition is probably only one of the required abilities, the relationship could be more complicated. Interestingly, we have heard several times from different airport supervisors that they believe women are better in x-ray screening than men, because they usually find more prohibited items.

The goal of this study was to investigate whether age and gender affect performance in x-ray screening. Performance in x-ray screening was measured with the X-Ray Object Recognition Test, X-Ray ORT [1], [2]. It has been developed to measure the screener's ability to cope with image-based factors such as rotation, superposition and bag complexity. The X-Ray ORT contains images of bags with either a gun or a knife or no prohibited item in it. The research questions are (1) whether an influence of age on detection performance (sensitivity) and response bias can be found, and (2) whether there is a gender difference in these two measures.

II. METHOD

A. Participants

A total of 410 screeners of Zurich Airport Unique at the age of 24 to 65 completed the test. Screeners were part of two different groups: cabin baggage screeners (CBS) and hold baggage screeners (HBS).

We only used data of screeners who worked more than an average of 30 percent in the past four years to make sure that all participants were working on a regular basis. With this constraint the CBS group consisted of 308 screeners (96 men, 212 women). The total number of HBS screeners was 84, i.e. 27 men and 57 women.

B. Materials and Procedure

As explained above, the X-Ray ORT, a computer-based x-ray screening test, was used in this study [1], [2]. The task in this test consists of finding weapons in x-ray images of bags. A total of 16 weapons is used, eight images of guns and eight images of knives. Before test start, all guns and knives are shown for 10 seconds on the screen, respectively. This is done in order to make sure that people are familiar with the weapons they have to look for in the test trials. There is an introductory phase with two guns and two knives that are not used in the test phase. Every threat item is shown in a rotated and in a non-rotated view. The images also vary systematically in bag complexity and superposition. Images are in black-and-white. There are a total of 256 trials: 2 weapons (guns, knives) \* 8 (exemplars) \* 2 (views) \* 2 (bag complexities) \* 2 (superpositions) \* 2 (harmless vs. threat images). The trials are divided into four blocks with 64 trials each. The blocks are counterbalanced across participants using a Latin Square. Within each block the trials are presented in random order.

III. RESULTS

To measure the performance in the X-Ray ORT we used the measures  $A'$  and  $d'$  from signal detection theory [4] which are calculated from the hit and false alarm rate of each screener.

$A'$  is calculated with the following formula:

If  $H$  (hit rate) >  $F$  (false alarm rate):

$$A' = 0.5 + (H - F) * (1 + H - F) / [4 * H * (1 - F)]$$

If  $F > H$ :

$$A' = 0.5 - (F - H) * (1 + F - H) / [4 * F * (1 - H)]$$

In the following we report only  $A'$  scores unless the two measures differ in their levels of significance. To measure the subjective response bias we used the criterion measure  $B''$  which is also calculated from hit and false alarm rate as following:

If  $H$  (hit rate) >  $F$  (false alarm rate):

$$B'' = [H(1 - H) - F(1 - F)] / [H(1 - H) + F(1 - F)]$$

If  $F > H$ :

$$B'' = [F(1 - F) - H(1 - H)] / [F(1 - F) + H(1 - H)]$$

An outlier analysis was performed and we excluded values higher or lower than two standard deviations from the mean. This resulted in an exclusion of 14 CBS and 4 HBS participants for the analyses of detection performance and 13

CBS and 5 HBS screeners for the analyses of the response bias, which is about 5% of the data. Effect sizes  $\eta^2$  are reported and can be judged based on Cohen [26].

A. Age

An effect of age on detection performance was found. To extract the influence of how long people were employed as screeners we used partial correlations taking hours on job into account (working experience). Partial correlations between  $A'$  and age controlling for working experience showed that older people performed significantly worse both in the CBS group ( $r(294) = -.32, p < .01$ ) and the HBS group ( $r(80) = -.35, p < .01$ )<sup>1</sup>.

No influence of age was found concerning the subjective response bias. Partial correlations controlling for working experience were not significant for neither screener group (CBS:  $r(296) = -.03, p = .61$ ; HBS:  $r(79) = .18, p = .12$ ).

B. Gender differences

CBS men had an average detection performance of  $A' = .88$  whereas the average detection performance of women was  $A' = .87$ . Both groups had a standard deviation of  $SD = .03$ . An analysis of covariance (ANCOVA) with gender as between-participants factor, age and working experience as covariates, showed a small significant mean difference of gender with an effect size of  $\eta^2 = .02, F(1, 291) = 5.46, MSE = .001, p < .05$  for the CBS group. In the HBS group both males and females had an average detection performance of  $A' = .91$ . The ANCOVA with age and working experience as covariates was not significant and had an effect size of  $\eta^2 = .003, F(1, 76) = 0.26, MSE = .001, p = .62$ . For CBS, men had a positive mean response bias ( $M = .08, SD = .30$ ) whereas in women the response bias was negative ( $M = -.08, SD = .29$ ). An ANCOVA with gender as between-participants factor, age and working experience as covariates showed that this difference was significant ( $\eta^2 = .06, F(1, 292) = 18.76, MSE = .09, p < .001$ ). There was also a very similar gender difference regarding the response bias for the HBS group (men:  $M = .07, SD = .21$ ; women:  $M = -.04, SD = .30$ , analysis of covariance:  $\eta^2 = .07, F(1, 75) = 5.54, MSE = .07, p < .05$ ).

IV. DISCUSSION

In this study we examined the influence of age and gender on the detection performance (sensitivity) and the subjective response bias in x-ray screening. For this purpose a computer-based test, the X-Ray ORT was used (for details see [2]).

A negative effect of age on performance was found. Older screeners performed significantly worse in the x-ray screening test. This result coincides with literature on cognition and aging, e.g., [9], [14].

Gender had a small effect, but only in the CBS group. Men performed slightly better in the X-Ray ORT. This result also corresponds with previous research in this field, e.g., [14], [19], [20], [21]. However, the effect is small, as the effect size

<sup>1</sup> Partial correlation between  $d'$  and age:  $r(78) = -.25, p < .05$

of  $\eta^2 = .02$  clearly shows. In the HBS group no gender difference was found ( $\eta^2 = .003$ ).

Women had a significantly lower response bias in both groups, CBS and HBS. This means that on average, women tend to give more often the answer that the bag is not ok. This results in a higher false alarm rate but also in a higher hit rate. If the same happens when working at the checkpoint, they would open more bags and therefore find more prohibited objects. This would explain why supervisors at airport security checkpoints sometimes claim that women find more prohibited items. Some earlier studies have indeed reported that women tend to be more risk averse than men (see [27] for a meta-analysis). This would account for the difference in the response bias between female and male screeners.

The results of this study correspond for the most part with results of cognition-related research. As explained in the introduction, X-ray screening involves several cognitive functions. Earlier research has shown that certain cognitive functions are affected by aging [6], [9]. In this study we also found a decrease of detection performance in terms of sensitivity. But we do not yet know which functions are most important for detection performance. Obviously older people could not compensate for their deficits. It seems that they had no more domain knowledge than younger participants or that this domain knowledge could not be used in order to compensate for impaired detection performance. However, we must be cautious regarding the implications for real life screening operations of these results. Compared to training effects, the influence of age is rather small. Ghylis, Drury and Schwaninger reported huge training effects when screeners used an individually adaptive computer based training system, X-Ray Tutor. The effect size was  $\eta^2 = .505$ , which was 50 times larger than the age effect ( $\eta^2 = .011$ ) [28].

As we have seen gender differences are also rather small. Research about cognitive gender differences suggests that men perform better in spatial tasks [20]. X-ray screening is quite a complex process and requires probably a variety of different abilities and maybe not only spatial cognition abilities.

It is important for aviation security to know on what factors detection in x-ray screening depends. The cognitive processes which underlie this task must be understood. If we know what abilities are essential, how these abilities are influenced, and how they can be improved, selection and training of screeners can be as effective as possible.

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