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Stress-induced cortisol secretion impairs detection performance in x-ray baggage screening for hidden weapons by screening novices

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Abstract

Aviation security strongly depends on screeners' performance in the detection of threat objects in x-ray images of passenger bags. We examined for the first time the effects of stress and stress-induced cortisol increases on detection performance of hidden weapons in an x-ray baggage screening task. We randomly assigned 48 participants either to a stress or a nonstress group. The stress group was exposed to a standardized psychosocial stress test (TSST). Before and after stress/nonstress, participants had to detect threat objects in a computer-based object recognition test (X-ray ORT). We repeatedly measured salivary cortisol and X-ray ORT performance before and after stress/nonstress. Cortisol increases in reaction to psychosocial stress induction but not to nonstress independently impaired x-ray detection performance. Our results suggest that stress-induced cortisol increases at peak reactivity impair x-ray screening performance.

Descriptors: X-ray baggage screening, Cortisol, Stress, TSST, X-ray ORT, Airport security, Human factors, Detection performance

Terror attacks in civil aviation demonstrate the importance of effective x-ray screening of passenger bags in preventing terrorists from bringing threat objects on board of an airplane. Although technological progress provides airport security with advanced x-ray screening systems, the final decision still relies on human operators (Bolfing, Halbherr, & Schwaninger, 2008; Schwaninger, 2006, 2009).

Human detection of threats in x-ray images of passenger bags requires not only knowledge-based expertise in terms of experience-related visual knowledge and its cognitive processing but also abilities to cope with image-based factors in x-ray images (Hardmeier & Schwaninger, 2008; Schwaninger, Hardmeier, & Hofer, 2005). Experience-related visual knowledge relevant for x-ray baggage screening comprises knowledge regarding kinds of prohibited threat items and their visual representation in x-ray images. Cognitive processing of this knowledge includes its retrieval from memory and recognition of potential threat items by comparing x-ray images with memorized visual representations of prohibited threat items (Schwaninger et al., 2005). Image-based factors in x-ray images that influence screening performance include view difficulty, superposition, and bag complexity (Schwaninger et al., 2005). An object is more difficult to detect if depicted from an unusual viewpoint (view difficulty), if superimposed by other objects (superposition), or if shown in close-packed bags with many other items (bag complexity). Abilities to cope with these image-based factors during x-ray object recognition relate to visual and spatial cognition such as visual search, figure ground segregation, mental rotation, and to the working memory (Hardmeier & Schwaninger, 2008; Riegelnig & Schwaninger, 2006).

Psychosocial stress may also impact x-ray detection performance. Airport security screeners are likely to experience psychosocial stress at work. They often work under a high level of noise and time pressure. Within a few seconds, they have to judge whether a bag can enter the airplane or not (Bolfing & Schwaninger, 2009), and failure of detection of a threat item may have disastrous consequences. Moreover, screeners frequently have to cope with impatient travelers or travelers under time pressure and their negative feedback, especially in the case of long passenger waiting lines (Bolfing & Schwaninger, 2009). Thus, airport security screeners' working environment is characterized by

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situational components including anticipation of negative consequences, social-evaluative threat, ego involvement, and motivated performance, but also ambiguity or unpredictability that typically induce psychosocial stress reactions (Dickerson & Kemeny, 2004; Mason, 1968).

Hitherto, it is unclear whether psychosocial stress impacts x-ray detection performance. Here, we argue that psychosocial stress may impair x-ray detection performance by releasing glucocorticoids due to the following reasoning: Stress situations characterized by the described situational components activate the hypothalamus-pituitary-adrenal (HPA) axis with the glucocorticoid (GC) cortisol as end product (Dickerson & Kemeny, 2004). Cortisol can cross the blood-brain barrier and access the brain to influence cognitive functions (de Kloet, Oitzl, & Joels, 1999). Human studies show that acute increases in GCs affect cognitive functions relevant for optimal x-ray screening of passenger bags. Both exogenously (i.e., by GC administration) and endogenously (i.e., by stress induction), induced acute GC level increases consistently impair memory retrieval (de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Kuhlmann, Piel, & Wolf, 2005), most likely in a dose-dependent manner (de Quervain et al., 2000; Kirschbaum et al., 1996). More specifically, oral administration of 25 mg cortisone significantly impaired memory retrieval 1 h later, that is, at a time when resulting increases in salivary cortisol concentrations are comparable to peak concentrations induced by psychosocial stress (Kirschbaum et al., 1996). Notably, the impairing effect on memory retrieval was not observed 24 h after oral cortisone administration when administration-induced cortisol increases returned to baseline levels (de Quervain et al., 2000). Furthermore, studies applying stress paradigms to induce GC increases suggest that stress effects on memory retrieval depend on the height of circulating GC levels at the time of their stress peak, that is, on maximum stress reactivity GC increases (Kirschbaum et al., 1996; Kuhlmann et al., 2005). Results showed a significant negative relationship between stress-induced cortisol levels and retrieval, indicating that higher stress-induced cortisol levels lead to poorer retrieval performance (Kirschbaum et al., 1996). Notably, with respect to the valence of tested memory material, the retrieval of valenced material (positive and/or negative words) seems to be more affected by GC increases than the retrieval of neutral material (neutral words) (Domes, Heinrichs, Rimmele, Reichwald, & Hautzinger, 2004; Kuhlmann et al., 2005). Given the supposedly negative valence of threat items such as weapons, these GC effects may also apply to x-ray detection performance. Moreover, acute elevation of glucocorticoids impairs both declarative memory and (although not unequivocally, see Kuhlmann et al., 2005; Monk & Nelson, 2002) working memory, with working memory being more sensitive to GC effects (Hsu, Garside, Massey, & McAllister-Williams, 2003; Lupien, Gillin, & Hauger, 1999; Oei, Everaerd, Elzinga, van Well, & Bermond, 2006; Schoofs, Preuss, & Wolf, 2008; Schoofs, Wolf, & Smeets, 2009; Wolf et al., 2001). Interestingly, observations from unexpected workplace covert tests implicate unpredictability stress to impair x-ray screening performance in x-ray baggage screening (Schwaninger, 2009), but studies systematically investigating effects of stress induction or stress-induced GC increases on x-ray detection performance are missing.

The aim of this study was to investigate in novices the effects of psychosocial stress-induced cortisol secretion on detection performance in an x-ray baggage screening task. Given the described stress and/or GC-induced impairment of cognitive functions relevant for optimal x-ray screening of passenger bags (especially in cases of processing valenced material such as threat items), we hypothesized that psychosocial stress but not nonstress would impair x-ray detection performance by stress-induced increases in cortisol. We randomly assigned healthy men either to a nonstress reading group or a stress group exposed to the Trier Social Stress Test (TSST) as a standardized and well-validated stressor. We repeatedly assessed x-ray detection performance by means of the X-ray Object Recognition Test (X-ray ORT, Hardmeier, Hofer, & Schwaninger, 2005; Schwaninger, 2003) and salivary cortisol before and after stress or nonstress, respectively. Potential confounders of X-ray ORT detection performance were controlled.

Method

Study Participants

The final study sample consisted of 48 apparently healthy men without prior experience in x-ray baggage screening. We recruited healthy male participants aged between 18 and 40 years with normal or corrected-to-normal vision by advertisement at the University of Zurich. All individuals expressing interest in participating were screened by a telephone interview using an extensive health questionnaire (Wirtz, von Kanel, Frey, Ehlert, & Fischer, 2004; Wirtz et al., 2003). Specific exclusion criteria as obtained by participants' self-report were the following: clinical psychosomatic and psychiatric disorders, regular or occasional intake of medication, heart disease, hypertension, varicosis, thrombotic diseases, elevated blood sugar and diabetes, elevated cholesterol, liver and renal diseases, chronic obstructive pulmonary disease, allergies and atopic diathesis, rheumatic diseases, HIV, cancer, current infectious diseases, alcohol and illicit drug abuse, smoking more than four cigarettes per day, previous participation in stress research projects using stress induction by TSST (see below), or previous practical experience with our x-ray screening task (X-ray ORT, see below). Participants who fulfilled all criteria and were willing to participate were entered into the study until a total sample size of 48 men was successfully recruited. Included participants were provided with complete written and oral descriptions of the study. The study was approved by the local institutional review board, and informed written consent was obtained before participating. Participation was remunerated with research participation credit points or 40 Swiss francs.

Design and Procedures

Forty-eight eligible participants were randomly assigned to either a stress ($n = 24$) or a nonstress group ($n = 24$). Participants in both groups took part in the experimental session consisting of three main parts: (1) assessment of X-ray ORT detection performance before stress/nonstress, (2) nonstress condition or psychosocial stress induction (TSST), and (3) assessment of X-ray ORT detection performance after stress/nonstress. In detail, participants arrived in the lab between 13:00 and 14:30 after having abstained from food and drinks other than water for 1 h, from beverages with caffeine or alcohol since the previous evening, and from strenuous physical activity for 48 h prior to study participation. In order to ensure that all participants encountered the same condition during the baseline assessment period independent of their group assignment, they were all told that they would be subjected to a challenging task without providing any further details. After arrival participants were welcomed and seated in a quiet room for 25 min.

Then, concentration performance was measured using the d2 Test of Attention (see below). Thirty minutes after arrival, participants entered a second quiet room used for X-ray ORT assessment. There, they completed the first two blocks (X-ray ORT-A, X-ray ORT-B) of the X-ray ORT (see below) with a duration of 10 min per block and a short break between blocks to assess both individual baseline X-ray ORT detection performance (X-ray ORT-A) and individual learning effects in X-ray ORT detection performance (increase in X-ray ORT detection performance by calculating X-ray ORT-B minus X-ray ORT-A). Next, half of the participants were exposed to acute psychosocial stress using the TSST (see below) in a separate room, while the other half was assigned to calm reading of newspapers and magazines (nonstress condition) in the first quiet room for 20 min. Immediately thereafter, all participants completed the second two blocks of the X-ray ORT (X-ray ORT-C, X-ray ORT-D) with a duration of 10 min per block and a short break between blocks in the second quiet room. We decided for these two poststress/nonstress X-ray ORT assessments to obtain X-ray ORT detection performance measurements at different time points in the cortisol stress reactivity kinetics reflecting initial cortisol stress reactivity where cortisol levels are still relatively low (X-ray ORT-C, from immediately after stress to 10 min after TSST stress cessation) and maximum (or peak) cortisol stress reactivity (X-ray ORT-D, 10 to 20 min after TSST) (Kirschbaum et al., 1993; Wirtz et al., 2013). Two saliva samples for measuring salivary cortisol were taken at baseline, that is, prior to the d2 Test of Attention, and 1 min prior to beginning of the stress or nonstress condition. Saliva samples for poststress/nonstress cortisol assessment were taken immediately (+1 min), and 10, 20, 30, 40, 50, and 60 min after stress or nonstress cessation.

X-ray Object Recognition Test (X-ray ORT)

Description. In order to assess visual x-ray detection performance, we used the X-ray Object Recognition Test (X-ray ORT, Hardmeier et al., 2005; Schwaninger, 2003). The X-ray ORT is a realistic, reliable, and valid instrument for measuring visual abilities needed to detect weapons (guns and knives) in x-ray images of passenger bags (i.e., threat items). The fully computer-based test consists of 256 x-ray images of passenger bags with 128 bags containing a threat item while the other 128 bags do not. Each image was presented for 4 s on a computer screen, and participants had to decide whether the bag was without a threat item (OK) or contained a threat item (NOT OK). They also had to indicate how sure they were in their decision (OK vs. NOT OK) on a 90-point rating scale.

To reduce the influence of knowledge-based factors, all threat items were presented for 10 s before the actual test began. Threat items consisted of 8 guns and 8 knives as weapons that are familiar to most people independent of training or visual experience. Moreover, as x-ray screening novices do not know how to interpret color information, images were shown in black and white to eliminate color-diagnostic information.

The X-ray ORT systematically varies the three image-based factors bag viewpoint, superposition, and complexity. Each threat item was presented in both an easy (frontal) and a difficult (rotated) view. Each of these viewpoint variations was presented more or less superimposed by other objects. Finally, each of these four variations per threat item was additionally presented in bags of low complexity levels (fewer items in the bag) and bags with high complexity levels (more items in the bag). This image-based factor variation procedure renders eight different variations of the 16 different threat items that add up to a total of 128 bags containing threat items.

For the purpose of our study, the test was divided into four blocks, numbered 1, 2, 3, and 4. Each of these numbered blocks consisted of 64 images and lasted for 10 min. Numbered blocks were balanced according to viewpoint, superposition, and bag complexity. In order to avoid potential sequence effects, the four numbered blocks were counterbalanced using a 4×4 Williams Latin square design across all participants, which resulted in four possible numbered block sequences (1-2-3-4, 2-4-1-3, 3-1-4-2, and 4-3-2-1). Each numbered block sequence was equally repeated in the stress and nonstress group (i.e., 6 times each) and throughout the overall experiment (i.e., 12 times). Independent of block number (i.e., 1,2,3, or 4), X-ray ORT-blocks were denoted with the letters A, B, C, and D based on the chronological presentation order in the experiment: X-ray ORT-A and X-ray ORT-B were completed before TSST or reading (prestress/nonstress: X-ray ORT-A, X-ray ORT-B) and X-ray ORT-C and X-ray ORT-D followed immediately after TSST or reading cessation (poststress/nonstress: X-ray ORT-C and X-ray ORT-D). Exact presentation times in relation to TSST/nonstress are described in Design and Procedures above.

Measure of Detection Performance A′. As a measure for x-ray detection performance, we followed previous research using the X-ray ORT (Hardmeier et al., 2005; Hardmeier, Hofer, & Schwaninger, 2006; Schwaninger et al., 2005) and used the well-accepted nonparametric detection performance measure A′ (Pollack & Norman, 1964) as our main dependent detection performance variable. A′ can be calculated by the following formula (Grier, 1971):

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

H represents the hit rate and F the false alarm rate. If the false alarm rate is greater than the hit rate, the equation must be modified (Aaronson & Watts, 1987; Snodgrass & Corwin, 1988):

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

The performance measure A′ combines the following advantages: the calculation is based both on hits (i.e., correct identification of a threat item) and false alarms (i.e., incorrectly identifying a threat item in a bag without a threat item). This is important as a screener who judges almost all bags as NOT OK would certainly have a high hit rate, but also a very high false alarm rate and thereby be very inefficient. Moreover, A′ ranges from 0.5 (chance performance) to 1.0 (perfect performance) and is therefore very descriptive and easy to interpret. In addition, A′ requires no a priori assumption regarding the underlying noise and signal-plus-noise distributions: it can be calculated without ROC curves and independent of the normal distribution and equal variance assumptions of the signal-noise and noise distribution (Hofer & Schwaninger, 2004; Stanislaw & Todorov, 1999).

Potential Confounding Variables of X-ray Detection Performance

Based on previous findings and theoretical considerations, we controlled for the following variables as an a priori defined set of confounders: X-ray ORT-A (i.e., baseline x-ray detection performance), X-ray ORT learning (i.e., learning effects in X-ray ORT detection performance calculated as the increase in X-ray ORT

detection performance by subtracting X-ray ORT-A from X-ray ORT-B), concentration performance (i.e., d2-CP), baseline cortisol levels (i.e., cortisol peak level (10 min poststress/nonstress) minus cortisol baseline), and age.

X-ray ORT-A was controlled to rule out potential confounding influences of large interindividual baseline differences in x-ray detection performance as measured by X-ray ORT observed in novices (Schwaninger et al., 2005). X-ray ORT learning was controlled to take into account potential learning effects in x-ray detection performance as observed in prior studies (Schwaninger et al., 2005; Schwaninger, Hardmeier, Riegelnig, & Martin, 2010). Concentration performance as a measure of attention (see below) was controlled due to documented associations with x-ray detection performance (Hardmeier & Schwaninger, 2008). Cortisol baseline levels were controlled as cortisol nonstress levels have been associated with measures assessing different aspects of cognitive functions (Lee et al., 2007; MacLullich et al., 2005) that in turn relate to detection performance (Hardmeier & Schwaninger, 2008). Finally, age was controlled as it strongly related to X-ray ORT detection performance (Riegelnig & Schwaninger, 2006; Schwaninger et al., 2010).

Psychosocial Stress Induction

To inflict psychosocial stress, we used the well-standardized Trier Social Stress Test (TSST) comprising a 5-min preparation phase following a short introduction, a subsequent 5-min mock job interview, and a 5-min mental arithmetic task in front of an unknown panel of two evaluators and a conspicuous video camera and microphone (Kirschbaum et al., 1993). The panel members were dressed in white laboratory coats and were presented as experts in evaluation of nonverbal behavior. The TSST enables a natural exposure to a psychosocially stressful situation and has repeatedly been found to induce profound endocrine and cardiovascular responses (Dickerson & Kemeny, 2004; Kirschbaum et al., 1993).

Cortisol Measurements

For assessment of salivary-free cortisol levels, saliva was collected using Salivette collection devices (Sarstedt, Rommelsdorf, Germany) and stored at −20°C until biochemical analysis. To prepare for biochemical analysis, saliva samples were thawed and centrifuged at 3,000 rpm for 10 min to yield low viscosity saliva. Salivary-free cortisol concentrations were measured using a commercially available chemiluminescence immunoassay with high sensitivity of 0.16 ng/ml (LIA; IBL Hamburg, Germany). Inter- and intra-assay variability was below 11.5% and 7.7%, respectively.

Measure of Concentration Performance

Concentration performance was assessed using the d2 Test of Attention (Brickenkamp, 1994), a paper and pencil letter-cancellation test. The task is to discriminate and cancel targets from visually similar distractors. The test consists of 14 lines of 47 randomly mixed letters each. The letters are either "d" or "p" with one, two, three or four small quotation marks. Participants were instructed to mark the letter d with 2 quotation marks (target) as fast and as accurately as possible, and to start with the next line when requested by the experimenter. The test lasts for 4.40 min (Brickenkamp, 1994). Concentration performance (d2-CP) is computed by the number of correctly cancelled targets minus the number of incorrectly cancelled letters (Bates & Lemay, 2004).

Table 1. *Participant Characteristics of the Stress Group and the Nonstress Group*

	Stress group ($n = 24$)	Nonstress group ($n = 24$)	p
Age (years)	24.33 ± 4.37	24.79 ± 4.61	.73
X-ray ORT-A	.80 ± .06	.81 ± 0.06	.45
X-ray ORT learning	.04 ± 0.08	.03 ± 0.06	.80
Concentration performance	278.50 ± 16.32	262.38 ± 24.64	.010
Cortisol baseline levels (nmol/l)	7.76 ± 7.21	10.10 ± 5.28	.027
Maximum cortisol change (nmol/l)	5.21 ± 7.22	−4.80 ± 3.27	< .001

Note. Values are given as means ± *SEM* (range); *n*: valid cases; X-ray ORT-A = baseline X-ray ORT detection performance; X-ray ORT learning = learning effects in X-ray ORT detection performance; cortisol baseline levels = mean cortisol levels before stress; maximum cortisol change = cortisol levels 10 min poststress/nonstress minus cortisol baseline levels. Concentration performance was measured using d2 Test of Attention.

d2-CP reflects both the speed and the accuracy aspect of performance and is thereby less influenced by test-taking strategies (Bates & Lemay, 2004). The d2 Test of Attention is a reliable and valid instrument with the d2-CP measure showing a high internal reliability ($\alpha = .97$) (Bates & Lemay, 2004; Brickenkamp, 1994).

Statistical Analyses

Data were analyzed using SPSS (version 19) statistical software package for Macintosh (IBM SPSS Statistics, Somers, NY). The optimal sample size of $n = 48$ to detect an expected effect size of .35 in multiple regression analyses with a power of .85 (5 tested predictors and 7 predictors in total) was calculated a priori with the statistical software G-Power 3 (Faul, Erdfelder, Buchner, & Lang, 2009). All analyses were two-tailed, with the level of significance set at $p < .05$ and the level of marginal significance at $p < .10$. Results are shown as mean ± *SEM*. Data were tested for normal distribution and homogeneity of variance before statistical procedures were applied. Huynh-Feldt correction for repeated measures was applied where appropriate. Effect size parameters (*f*) were calculated from partial η^2 values and are reported where appropriate (effect size conventions: *f:* .10 = small, .25 = medium, .40 = large; see Cohen, 1988).

Maximum cortisol change was calculated as cortisol peak level (10 min poststress/nonstress) minus cortisol baseline, initial cortisol change was calculated as cortisol level immediately after stress minus cortisol baseline, and areas under the total cortisol response curve were calculated with respect to ground (AUCg) and with respect to increase (AUCi) using the trapezoid formula (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). Notably, whereas AUCg mostly captures baseline differences, AUCi is a measure reflecting differences between baseline and task values. To obtain a single cortisol baseline measure, we calculated the mean of the first two cortisol assessments obtained before stress/nonstress. As cortisol baseline levels were skewed, we log-transformed (log10) them and obtained a normal distribution (Crzu, 2007). Log-transformed cortisol baseline levels were used for modeling and testing regarding group characteristics and associations with x-ray detection performance. We depict untransformed data as means ± *SEM* in Table 1 and in Figure 1 for reasons of clarity.

We calculated univariate analyses of variance (ANOVAs) to test for group differences. As a manipulation check, we calculated

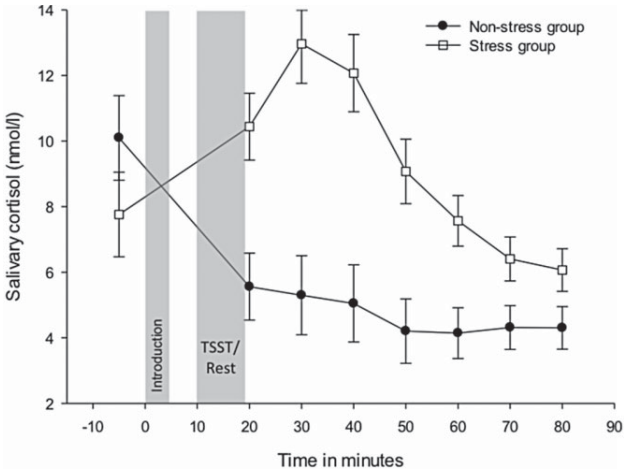

Figure 1. Changes in cortisol levels over time in the stress and nonstress group. Repeated measures ANOVA revealed that the groups significantly differed in repeated salivary-free cortisol levels over time (Interaction Group × Time: $F(2.49,114.33) = 17.38$, $p < .001$) indicating a successful induction of cortisol stress reactivity by the TSST in the stress group.

repeated measures ANOVA to test for changes in cortisol levels over time in the stress and nonstress group.

To test for possible condition only (i.e., stress, nonstress) effects on detection performance, we calculated repeated measures analysis of covariance (ANCOVA). We controlled for the following variables as an a priori defined set of confounders: X-ray ORT-A, X-ray ORT learning, age, concentration performance, and baseline cortisol levels as covariates.

We calculated linear regression analyses to test for associations between cortisol indices (i.e., maximum and initial cortisol changes, AUCi, AUCg, and baseline cortisol) and detection performance A′. To rule out a potential confounding by other variables and in order to avoid statistical overcontrolling given our sample size, we used a stepwise procedure to identify a maximum of 5 predictors using maximum cortisol change as the variable of major interest. Based on our sample size and the recommendation of 10 study participants per predictor (Babyak, 2004), we a priori restricted the number of predictors including control variables: In a first step, in addition to maximum cortisol change, we entered group, baseline cortisol levels, X-ray ORT-A, and concentration performance as an a priori defined set of predictor variables. In a second step, variables with low predictive power based on a conservatively chosen p value of $> .30$ (Wirtz et al., 2007) were excluded and replaced by age and X-ray ORT learning as two further a priori defined potential confounders. Again, predictors with $ps > .30$ were excluded where applicable. This procedure restricted the number of entered and thus tested predictors to a maximum of 5, given a maximum of 7 predictors in total. The final regression models for each cortisol measure thus included a maximum of 5 predictors with $ps < .30$. Significant independent predictions of A′ by cortisol indices were further tested by repeating the final regression models in each subject group separately. We expected higher maximum cortisol changes and accordingly AUCi, but none of the other cortisol indices, to significantly predict lower A′ X-ray ORT detection performance in the stress group but not in the nonstress group.

Explained variance of significant predictor variables in regression models is indicated by R^2 and/or R^2 change (ΔR^2).

Results

Characteristics of the Study Groups

Table 1 provides participants' characteristics of the stress group ($n = 24$) and the nonstress group ($n = 24$). All participants were nonsmokers. Univariate ANOVAs revealed that the two groups did not significantly differ in age, X-ray ORT-A, and in the extent of X-ray ORT learning (all $ps > .44$). However, the stress group displayed a significantly better concentration performance, lower cortisol baseline levels, and higher cortisol maximum changes as compared to the nonstress group ($ps \leq .027$, $fs > .34$).

Cortisol Levels Over Time in the Stress and Nonstress Group

As depicted in Figure 1, the study groups significantly differed in repeated salivary-free cortisol levels over time (Interaction Group × Time: $F(2.5,114.3) = 17.38$, $p < .001$, partial $\eta^2 = .27$, $f = .61$), indicating a successful induction of cortisol stress reactivity by the TSST in the stress group.

X-ray ORT Detection Performance Over Time in the Stress and Nonstress Group

Figure 2 depicts repeated X-ray ORT detection performance in the stress and the nonstress group. Repeated measures ANCOVA with group (stress vs. nonstress) as independent variable and the three repeated X-ray ORT detection performance measurements (X-ray ORT-B, X-ray ORT-C, and X-ray ORT-D) as repeated dependent variables revealed that the stress group had lower levels in X-ray ORT detection performance over time as compared to the nonstress group. The difference was marginally significant (main effect of group, $F(1,41) = 3.07$, $p = .087$, partial $\eta^2 = .07$, $f = .27$), while age, concentration performance, cortisol baseline levels, X-ray ORT-A, and X-ray ORT learning were controlled.

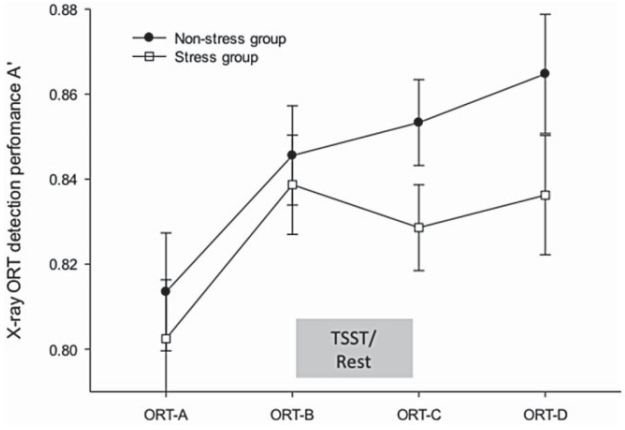

Figure 2. Repeated X-ray ORT detection performance (X-ray ORT-A, X-ray ORT-B, X-ray ORT-C, and X-ray ORT-D) in the stress and the nonstress group, while controlling for age, concentration performance, and cortisol baseline levels. Repeated measures ANCOVA revealed that the stress group had lower levels in X-ray ORT detection performance over time as compared to the nonstress group of borderline significance, while controlling for the full set of covariates (main effect of group, $F(1,41) = 3.07$, $p = .087$).

Table 2. *Results of the Final Multiple Linear Regression Model Predicting X-ray ORT Detection Performance (X-ray ORT-D)*

Variables entered	Standardized β-coefficient	*t*	*p* value	R^2 change
X-ray ORT-A	.57	3.48	.00	.17
Concentration performance	.28	2.33	.03	.08
Age	−.20	−1.67	.10	.04
X-ray ORT learning	.48	2.94	.01	.12
Maximum cortisol change	−.33	−2.65	.01	.10

Note. R^2 variance explained by the total model; R^2 change variance explained by the respective variable alone independent of all other entered predictors. X-ray ORT-D = X-ray ORT detection performance measured 10 to 20 min after TSST; X-ray ORT-A = baseline X-ray ORT detection performance; X-ray ORT learning = learning effects in X-ray ORT detection performance; maximum cortisol change = cortisol levels 10 min poststress/nonstress minus cortisol baseline levels. Concentration performance was measured using d2 Test of Attention.

Intervention (i.e., Stress or Nonstress)-Induced Cortisol Reactivity Indices and Subsequent X-ray ORT Detection Performance

To test our main hypothesis that stress/nonstress-induced maximum changes in cortisol relate to subsequent X-ray ORT detection performance, we calculated linear regression analyses with X-ray ORT-D detection performance assessed during highest salivary cortisol TSST stress responses (10 to 20 min after TSST stress cessation) as dependent variable and maximum cortisol change as the independent variable of interest. We then controlled for the first set of potential confounders (i.e., group, cortisol baseline levels, X-ray ORT-A, and concentration performance). Group and cortisol baseline levels showed low predictive power (*p*s > .30) and were therefore excluded and replaced by the second set of potential confounders consisting of age and X-ray ORT learning. As these two variables showed *p* values below .30, the final set of confounding variables consisted of X-ray ORT-A, concentration performance, age, and X-ray ORT learning. Stress-induced maximum cortisol changes significantly predicted X-ray ORT-D detection performance both without ($\beta = -.35$, $p = .015$, $R^2 = .12$) or with controlling for the first set of confounders ($\beta = -.46$, $p = .029$, $R^2 = .27$, $\Delta R^2 = .09$) as well as for the final set of confounding variables ($\beta = -.33$, $p = .011$, $R^2 = .41$, $\Delta R^2 = .10$, see Table 2, Figure 3). Similar results were obtained for cortisol AUCi as a measure reflecting differences between baseline and task values (without controlling for confounders: $\beta = -.31$, $p = .033$, $R^2 = .10$; with controlling for the final set of confounders: $\beta = -.35$, $p = .015$, $R^2 = .39$, $\Delta R^2 = .07$), but not for AUCg reflecting total cortisol output including baseline levels (*p*s ≥ .59).

With respect to separate reanalyses of the final regression models in the study groups, we found no significant associations between cortisol reactivity indices and X-ray ORT-D detection performance in the nonstress group (*p*s > .73). In the stress group, the associations were significant (maximum cortisol change: $\beta = -.28$, $p = .042$, $R^2 = .77$, $\Delta R^2 = .06$; AUCi: $\beta = -.28$, $p = .035$, $R^2 = .77$, $\Delta R^2 = .07$).

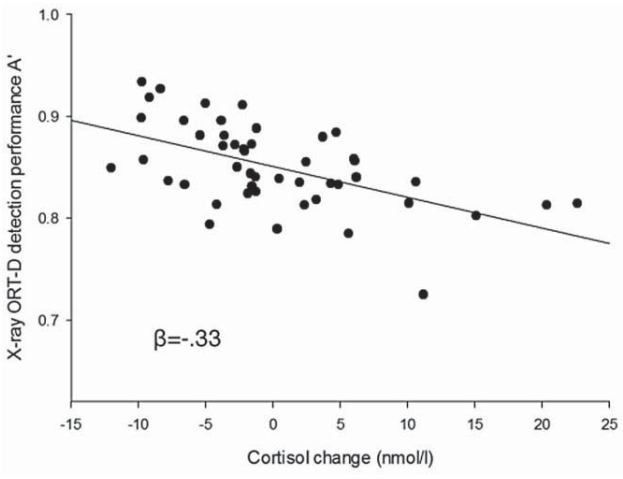

Figure 3. Independent association between maximum cortisol change as the predictor of interest and x-ray detection performance (X-ray ORT-D) as dependent variable according to the final regression model. Age, X-ray ORT-A, concentration performance, and ORT learning were controlled.

Intervention (i.e., Stress or Nonstress)-Induced Initial Cortisol Changes and Subsequent X-ray ORT Detection Performance

Regarding our hypothesis that stress/nonstress-induced initial cortisol changes do not relate to lower X-ray ORT detection performance, linear regression analyses confirmed that initial cortisol change (supposed to represent early prepeak cortisol stress reactivity in the TSST group) from baseline to immediately after stress (1 min poststress peak level minus baseline level) was not associated with X-ray ORT detection performance (X-ray ORT-C), either with or without controlling for covariates (*p*s > .91).

Nonstress Cortisol Levels and X-ray ORT Detection Performance

To further test whether baseline cortisol levels relate to X-ray ORT detection performance, linear regression analysis showed that basal prestress cortisol levels were not associated with X-ray ORT detection performance either with or without controlling for the remaining covariates (*p*s > .31).

Discussion

This is the first randomized-controlled study to assess whether psychosocial stress impacts detection performance in an airport security x-ray baggage screening task and whether this relates to stress-induced increases of the stress hormone cortisol. We randomly assigned healthy men either to a nonstress or stress group (TSST) and repeatedly assessed X-ray ORT detection performance and salivary cortisol before and after stress or nonstress. As hypothesized, we found that psychosocial stress but not nonstress impaired x-ray detection performance by stress-induced cortisol increase measures in a dose-dependent manner.

Our study findings extend previous observations of human factors affecting x-ray detection performance (e.g., Bolfing et al.,

2008; Schwaninger, 2006, 2009), suggesting for the first time a substantial influence of stress-induced increases in salivary cortisol. More detailed analysis of the observed borderline significant overall effect of stress on X-ray ORT detection revealed that maximum cortisol increases in reaction to stress as well as cortisol AUCi measures impaired X-ray ORT-D detection performance, notably in a linear manner, both with or without controlling for confounders. In contrast, total cortisol secretion (AUCg) was not associated with X-ray ORT-D detection performance, and changes in cortisol and X-ray ORT-D detection performance were unrelated in the nonstress group. Remarkably, 10% of variance in X-ray ORT detection performance was independently explained by nonstress/stress-induced maximum cortisol changes. Moreover, there was no association between x-ray detection performance and cortisol at the time of initial cortisol stress reactivity or at baseline. In sum, these findings indicate that neither the psychosocially stressful situation per se nor basal cortisol levels or initial or total cortisol secretion impair x-ray detection performance. The impairing effect seems to depend on the cortisol response to a stress-inducing situation and to occur at a time when cortisol levels were highest. In other words, the higher peak cortisol increases to acute psychosocial stress the more impaired is x-ray detection performance.

How do these findings compare with the literature and what are the resulting potential implications? Our findings of significant associations between higher stress-induced cortisol increases and impaired X-ray ORT-D detection performance are in line with results of previous research investigating influences of stress and stress-induced GC increases on cognition: As described before, optimal x-ray detection performance requires several cognitive functions including working memory, memory retrieval, and object recognition (Hardmeier & Schwaninger, 2008; Riegelnig & Schwaninger, 2006; Schwaninger et al., 2005). Indeed, previous research has shown that these cognitive functions can be impaired by GC increases (de Quervain et al., 2000; Hsu et al., 2003; Kirschbaum et al., 1996; Kuhlmann et al., 2005; Lupien et al., 1999) particularly when endogenous GC increases are high (Kirschbaum et al., 1996; Kuhlmann et al., 2005) and/or the memorized material is valenced (positive and/or negative words; de Quervain et al., 2000; Domes et al., 2004; Kuhlmann et al., 2005).

Moreover, our study identified X-ray ORT-A, X-ray ORT learning, concentration performance, and age as further predictors of X-ray ORT detection performance. X-ray ORT-A independently explained 17% of X-ray ORT-D detection performance variance, indicating that lower baseline abilities in X-ray ORT (X-ray ORT-A) related to poorer X-ray ORT-D performance. This finding corresponds to earlier observations that better baseline X-ray ORT performance related to faster improvement in x-ray screening performance (Hardmeier et al., 2006). Moreover, we found that stronger learning effects predicted higher X-ray ORT-D performance. X-ray ORT learning independently explained 12% of X-ray ORT-D detection performance indicating remarkable learning effects in X-ray ORT detection performance. This finding is in line with reported learning effects in X-ray ORT (Schwaninger et al., 2005), although in our study associations between learning effects and X-ray ORT detection performance are stronger. Notably, that study assessed X-ray ORT learning effects indirectly by comparing novices and professionals (with months or years of x-ray screening experience), whereas we investigated learning effects between X-ray ORT detection performance tests passed within 20 min in novices only. We therefore assume that initial strong learning effects in novices mainly occur over a short time span, especially during the first testing times, whereas learning effects become smaller with increasing x-ray screening experience when performance quality reaches a stable level. Furthermore, we found that higher attention as measured by concentration performance and younger age independently predicted higher X-ray ORT-D detection performance. Attention explained 8% and age 4% of X-ray ORT-D detection performance variance in accordance with previous studies reporting that higher attention scores and younger age relate to better x-ray baggage screening performance (Hardmeier & Schwaninger, 2008; Riegelnig & Schwaninger, 2006; Schwaninger et al., 2010).

Our findings may have implications for professional x-ray screening. For aviation security, identification of determinants of x-ray screening performance is of particular importance. Hitherto, selection of the most "talented" x-ray screening applicants (in terms of visual abilities needed to cope with image-based factors) and training of visual knowledge is practiced (Bolfing & Schwaninger, 2009; Halbherr, Schwaninger, Budgell, & Wales, 2013). However, as shown by covert tests, these activities are insufficient to guarantee that screeners act correctly when confronted with real threat items at a security checkpoint, especially when exposed to something unexpected (Schwaninger, 2009; Wetter, Hardmeier, & Hofer, 2008). This points to the importance of gaining knowledge about further factors that may influence x-ray screening performance and how potential impairing effects can be prevented. Our findings of impaired X-ray ORT detection performance by stress-induced cortisol increases indicate that efforts to reduce stress both on a situational level (e.g., at the security checkpoint) and on a personal level (e.g., by specific stress management in screeners' education and training) may contribute to increased x-ray screening efficiency and aviation security. Moreover, our finding that higher concentration performance increases detection performance may suggest that attention tests could serve as a helpful selection tool.

Our study has several limitations. First, our results are restricted to a group of healthy young to middle-aged men. They cannot be generalized to other groups with less advantageous health conditions or to women. The latter would be of interest given that a considerable number of x-ray screening professionals are female. Second, we measured salivary-free cortisol as an indicator of the HPA axis response to stress. While salivary-free cortisol has been shown to be a valid and reliable endocrine marker of HPA axis activity and reactivity (Kirschbaum & Hellhammer, 1994), other endocrine (e.g., epinephrine, norepinephrine, plasma cortisol) or stress-responsive psychological parameters or stress reactive systems still need to be examined. Third, our results are restricted to novices. For this initial investigation, we decided to investigate healthy men without previous experience in x-ray screening as subjects to avoid any potential confounding effects of sex, adverse health state, medication, and prior experience in x-ray baggage screening. However, the effects of acute stress-induced cortisol increases on x-ray screening performance in aviation security x-ray screeners still need to be investigated in future research. Fourth, although we consider airport baggage screening likely to induce stress (see introduction), its stressfulness has not yet been empirically studied to the best of our knowledge. Fifth, participant recruitment was based on self-report data regarding exclusion and inclusion criteria.

Our study also has several strengths. First, with the X-ray ORT, we used a reliable and valid test to assess x-ray detection performance (Hardmeier et al., 2005, 2006; Schwaninger et al., 2005). The X-ray ORT realistically presents x-ray images of passenger bags and is convenient for novices as the choice of well-known

threat items reduces a potentially confounding influence of knowledge-based factors. Moreover, detection performance measured by the X-ray ORT is an important determinant of on-the-job performance (Hardmeier et al., 2005), and it correlates well with tests convenient for professional x-ray screeners such as the Prohibited Item Test (PIT, Schwaninger et al., 2005) that to a stronger extent relates to knowledge-based factors (Hardmeier et al., 2006). Future studies are needed to investigate whether our findings also apply to professional screeners both in X-ray ORT and/or PIT performance. As in the PIT, retrieval of memorized prohibited items plays an important role and, given the reported impairing effect of GC increases on memory retrieval, we hypothesize that psychosocial stress would also impact PIT performance. Notably, we abstained from using the PIT in this study since our participants were screening novices without the required prior knowledge needed for adequate PIT performance. Second, the four X-ray ORT assessments (prenonstress/prestress: X-ray ORT-A and X-ray ORT-B, postnonstress/poststress: X-ray ORT-C and X-ray ORT-D) allow us to not only investigate the influence of cortisol change on X-ray ORT detection performance at two different time points in the cortisol stress reactivity kinetic (i.e., initial cortisol stress reactivity, [X-ray ORT-C] and maximum or peak cortisol stress reactivity [X-ray ORT-D]) but also to control for two important predictor variables (i.e., X-ray ORT baseline ability [X-ray ORT-A] and learning effects [X-ray ORT-B minus X-ray ORT-A]). Third, for inducing the stress response, we used a well-validated standardized acute psychosocial stress task (Dickerson & Kemeny, 2004; Kirschbaum et al., 1993). Notably, the impact of aviation baggage screening stress on detection performance still needs to be investigated. Fourth, we assessed a broad range of potential confounding variables of x-ray detection performance (i.e., X-ray ORT-A, X-ray ORT learning, concentration performance, baseline cortisol levels, and age). This allowed us to rule out potential confounding influences of these variables and to determine the predictive value of these candidate X-ray ORT detection performance predictors.

In conclusion, our results consistently suggest that psychosocial stress impairs x-ray screening performance by cortisol increases at a time when cortisol stress reactivity peaks. This may point to a role of stress prevention at the security checkpoint and of stress-management training in education and training of x-ray screeners to contribute to enhancing x-ray screening efficiency and aviation security. Future studies are needed to investigate the effects of acute stress-induced cortisol increases and of aviation baggage screening stress on x-ray screening performance in professional screeners.

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