Visual Cognition Abilities in X-Ray Screening

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Abstract — **The job of aviation security screeners is a highly demanding task. Based on the x-ray image of a passenger bag, a screener has to decide within few seconds only whether the bag is ok or has to be hand-searched. This x-ray screening task includes specific knowledge and visual cognition abilities. The knowledge about which items are prohibited and what they look like in x-ray images of passenger bags have to be learned on the job. In contrast the ability to cope with high bag complexity, superposition and viewpoint of threat items is relatively stable and can only be improved little with on the job training. Whether these abilities can be measured within a pre-employment assessment procedure using different subtests of well established intelligence test batteries was investigated in this study. Results revealed a relationship between the latent variable ability and detection performance in x-ray screening for both samples. However, 4 of the 12 intelligence tests are sufficient to explain detection performance in x-ray screening. The relationship between the latent variable ability, the X-Ray Object Recognition Test and detection performance later on the job was tested additionally.**

Abilities, aviation security, visual cognition, x-ray screening

I. INTRODUCTION

In recent years the importance of aviation security has increased enormously. To avoid that passengers bring potential threat items into the security restricted area and on board an airplane, body search and x-ray screening of passenger bags is essential. The x-ray screening task of aviation security screeners is very demanding and includes both specific knowledge and visual cognition abilities. Screeners have to acquire the knowledge about which items are prohibited and what they look like in x-ray images of passenger bags. This job and task specific knowledge and expertise respectively has to be learned after people got employed. Further, considering x-ray images different factors such as bag complexity, superposition and viewpoint of the threat items can influence the detection as well. Studies in this area could show that detection performance decreases significantly if threat items are shown in close-packed bags, if threats are more superimposed by other items and if they are shown in an unusual view. These effects were found for experts and novices. Furthermore, large individual differences could be seen for both, experienced aviation security screeners and novices [1]. Reference [1] defined these factors as image-based factors in x-ray screening. As they could be found for both groups, they are rather referred to relatively stable abilities than training. Therefore, it can be assumed that job applicants who are able to cope with these image-based factors perform better later on the job. Thus, measuring the ability to cope with image-based factors within a pre-employment assessment should increase detection performance later on the job remarkably.

Therefore, the X-Ray Object Recognition Test (X-Ray ORT), a reliable and valid x-ray screening test that measures image-based factors relatively independent of knowledge was developed [2]. Results could show that test results in the X-Ray ORT correlate significantly with threat image projection (TIP) data which measure detection performance on the job. Further, aviation security screeners who were selected with the X-Ray ORT performed in another x-ray screening test that measures all kind of prohibited items and was applied within the recurrent competency assessment significantly better than screeners who were not selected with this test [3].

However, the image-based factors should also be measurable with general visual cognition tests as these factors can be compared to the visual cognition processes visual search, figure-ground segregation and mental rotation that were investigated in many research studies. Furthermore, it can be expected that other abilities such logical thinking or concentration and vigilance play also an important role. For example the detection of improvised explosive devices (IEDs) which vary widely in shape and form, but share a common set of components differs from the detection of other prohibited items. As not one shape as a hole has to be detected, but the three components power source, detonator and explosive material, this task probably requires rather logical thinking. Moreover, screeners have to be constantly vigilant when performing the x-ray screening task. Therefore, a visual cognition test battery (CTB) including 12 tests that best match the x-ray screening task was applied within the pre-employment assessment additionally. Most tests are part of well established German intelligence test batteries. Four subtests of the Leistungsprüfsystem [4], three subtests of the Intelligenz Struktur Test 2000 (IST 2000) [5], the Raven's Advanced Progressive Matrices [6], the Frankfurter Aufmerksamkeits Inventar (FAIR) [7] and three tests which were developed by the University of Zurich [8] were used.

 ISBN: 978-0-615-20720-9

Tests from the visual CTB were expected to measure the following unobserved latent factors figure-ground segregation, visual search, mental rotation, spatial imagination, logical thinking and vigilance.

In a first step the influence of ability on detection performance in x-ray screening was investigated using the visual CTB. A common factor model was estimated to measure which tests in the visual CTB predict on the job performance best and can therefore be used as pre-employment assessment tool. Further, the common factor model which was estimated to measure the relationship between ability and detection performance in x-ray screening was validated by another sample. In terms of efficiency a possible shortening of the visual CTB was examined. Further, a full structural equation modeling (SEM) was estimated by defining the test results in the X-Ray ORT as additional indicator.

II. METHOD

A. Participants

The two samples used in this study consisted of 169 (*M* = 35.10, *SD* = 9.85; range 20 to 55 years) and 97 (*M* = 36.19, *SD* = 11.44; range 20 to 55 years) respectively job applicants who were employed as aviation security screeners based on their test results in the pre-employment assessment for aviation security screeners. The first sample (2006 Sample) consisted of 66 females and 103 males, the second sample (2007 Sample) of 51 females and 46 males. Part of the pre-employment assessment was the X-Ray ORT, the visual CTB, a German and English language test, a color blindness test, a physical examination test and a job interview. All results except for the visual CTB were used as selection criteria.

B. Measures

1) Visual Cognition Test Battery (CTB): The visual CTB consists of 12 tests which are mostly part of well established intelligence tests. All tests were conducted computer-based and not in the original paper-and-pencil form. To measure the second order factor ability, nine tests were assigned to the four first order factors figure-ground segregation, visual search, mental rotation and spatial imagination conducting Confirmatory Factor Analyses (CFAs). The remaining three tests Raven, Fair and a subtest of the IST 2000 (IST_MF) served as indicators.

a) Figure-ground segregation: The latent variable figure-ground segregation was measured with the LPS10 and the Noiser. The LPS10 is a subtest of the Leistungsprüfsystem [4], a major German intelligence test battery. It measures the ability to recognize a shape by ignoring irrelevant other features. Participants have to choose the only simple shape out of five which fits into the complex line drawing. The test includes 40 shapes of increasing complexity. Scored is the number of correct solutions that can be answered within 3 minutes. The Noiser was developed by the University of Zurich [8]. It measures how well people can recognize objects that are not fully visible. The test consists of 80 line drawings of simple objects which are increasingly destroyed (level of destruction: 75%, 80%, 85% and 90%). Trials are shown for 4 seconds only and then participants have to mark the correct term out of 20 choices. Scored is the number of correct choices.

b) Visual search: Visual search was measured with the Letter Search Test (LST) and the Image Comparison Test (ICT) [8]. The LST consists of a total of 60 trials. Participants have to find a lowercase letter within three-dimensional uppercase letters. There are three difficulty levels increasing in the number of uppercase letters. Each trial is presented for 5 seconds only, then participants have to decide whether there was a lowercase letter or not. Only fifty percent of all trials contain a target object. For analysis d' is calculated. The ICT comprises of two almost identical pictures that are presented next to each other. Participants have to mark all 15 differences within 3 minutes. Scored is the number of correct marked differences.

c) Mental rotation: The latent variable mental rotation was measured with the LPS7 and the Figurenauswahl (IST_FA) that are subtests of two major German intelligence test batteries, the Leistungsprüfsystem [4] and the Intelligenz-Struktur-Test (IST 2000) [5]. In the LPS7 participants have to mark the flipped number or letter in a row of equal but randomly rotated numbers or letters. Participants are given 2 minutes to complete as many trials as possible out of 40. Again, scored is the number of correct solutions. The IST_FA is about rearranging several pieces to one of five possible figures. The test consists of 20 trials that have to be solved within 7 minutes. Scored is the number of correctly answered trials.

d) Spatial imagination: Spatial imagination was measured with the LPS8, LPS9 of the Leistungsprüfsystem and the Würfelaufgabe (IST_WÜ) which is again a subtest of the IST 2000. The LPS8 consists of eight trials that have to be completed within 4 minutes. Participants have to mentally fold a leaf of paper into a defined form and determine for several sides which one of the leaf corresponds to the folded form. Again scored is the number of correct answers out of 40. The LPS9 measures spatial ability and asks participants to count the number of sides of three-dimensional geometric objects. Then they have to mark the correct number out of ten choices. Scored is the number of correctly marked numbers. The test duration is 3 minutes and maximum score is 40. Last, the subtest IST_WÜ consists of 20 trials that have to be completed within 9 minutes. Participants have to mentally rotate a cube and decide which of five alternatives match the target cube.

e) Raven: Logical thinking was measured using Raven's Advanced Progressive Matrices [6]. This test measures non-verbal deductive reasoning and visual discrimination. Participants have to complete a 3 * 3 matrix of abstract figures whereof the last figure in the lower right corner is missing. They can choose the right figure out of eight alternatives. The total of 47 used matrices increases in difficulty over time and the test duration is set to a maximum of 10 minutes. Again, scored is the number of correct solutions.

ISBN: 978-0-615-20720-9

f) Fair: The Frankfurter Aufmerksamkeits Inventar (FAIR) measures vigilance [7]. The task in this test is to discriminate between very similar looking signs as fast and accurate as possible. The participants are given 6 minutes to attend the test consisting of a total of 640 trials. The number of correctly detected targets as well as correctly rejected non-targets is used for analysis.

g) Merkfähigkeitstest (IST_MF): The IST_MF is as well a subtest of the IST 2000 and measures visual memory capacity [5]. This test that measures performance of short-term memory for figures consists of 13 pairs of symbols that have to be memorized within 1 minute. Then participants have to select the correct counterpart for all 13 symbols out of 5 alternatives within 3 minutes. Scored is the number of correct solutions.

2) Detection performance in x-ray screening: The detection performance in x-ray screening was measured with two x-ray screening tests and TIP data. The Prohibited Items Test (PIT) and the Bomb Detection Test (BDT) were part of the recurrent competency assessment which was conducted between 4 and 6 months after employment. Both tests are about recognizing threat items in x-ray images of passenger bags. Images were displayed for 10 and 15 seconds respectively on the screen. Then, participants have to answer whether the bag was OK (included no threat item) or NOT OK (included a threat item) by clicking on the button. Both, the prohibited items and bomb detection test differed in the 2006 and 2007 sample only insofar as other images were used. Results were calculated using d' which is a psychophysical measure and takes into account the hit and false alarm rate [9], [10]. For details about these x-ray screening tests, reliability and validity measures see [3], [11]. TIP is a technology which allows displaying fictional threat items into real passenger bags. That way, detection performance on the job can be measured. Again, d' was calculated and used as detection performance measure. For more information about TIP data see [12].

3) X-Ray Object Recognition Test (X-Ray ORT): The X-Ray ORT is an x-ray screening test which was developed to measure the ability to cope with image-based factors in x-ray screening relatively independent of knowledge. It consists of 256 x-ray images of passenger bags. Half of them contain either a gun or a knife. The other 128 images are harmless bags. Each bag is displayed for 4 seconds on the screen and then participants have to decide whether the bag was OK (no threat item) or NOT OK (a gun or knife) by clicking on the respective button. Detection performance was calculated using the detection performance measure d'. Test construction, its reliability and validity measures can be seen in [2], [3].

C. *Procedure*

The performance in the visual CTB and the X-Ray ORT was measured within the pre-employment assessment procedure. After employment all screeners had an initial training course which took three weeks. They also received training with the individual adaptive training system X-Ray Tutor (XRT). Screeners worked 4 to 6 months before they passed the first competency assessment which includes three x-ray screening tests and a theoretical exam on computer.

D. *Modeling Description*

The goal of this study was to test whether results in the single tests of the visual CTB show a relationship to detection performance in x-ray screening later on the job. The model was tested using a step-by-step procedure. First, CFAs were conducted to investigate how well the indicator variables accurately reflect the latent variables. Then, a common factor model was conducted for each group (2006 Sample, 2007 Sample). Second, a possible shortening of the visual CTB was tested. Third, a full structural equation modeling was conducted. As goodness-of-fit indices we report the sample-size-independent comparative fit index (CFI). Its values indicate a good fit the closer they are to one. According to [13] values greater or equal to .90 indicate acceptable model fit. We also report the root-mean-square error of approximation (RMSEA). RMSEA values less than or equal to .05 indicate good model fit. Furthermore, the information theoretical fit measures AIC, BCC, BIC and CAIC are reported because they are less sensitive to small sample size and are not based on statistical inference using probability theory (see [14]). All information theoretical fit measures should be substantially smaller than they are for the saturated model [15].

III. RESULTS

Table 1 shows descriptive statistics for all indicator variables. Table 2 and Table 3 depict the sample correlation matrix for the 2006 sample and for the 2007 sample, respectively (see Appendix).

We first specified a CFA model with the four first order factors figure-ground segregation, visual search, mental rotation, spatial imagination and the three indicators Raven, Fair, IST_MF to measure the second order factor ability. However, results indicate that the second order factor loadings between the second order factor ability and the four first order factors as well as the three indicators were all not significantly different from one. Thus, all 12 indicators load on one factor and there is no need to model separate factors. Furthermore, another first order factor named detection performance in x-ray screening was defined. This factor measured the detection performance in x-ray screening with the three indicators PIT, BDT and TIP. As can be seen in Figure 1, the common factor model includes the two first order factors ability and detection performance.

ISBN: 978-0-615-20720-9

TABLE I. RELIABILITIES, MEANS, STANDARD DEVIATIONS OF INDICATOR VARIABLES

Indicator variables	Reliability	2006 Sample (N = 169)		2007 Sample (N = 97)	
		M	*SD*	*M*	*SD*
LPS10	.83[c] / .69[c]	0.63	0.20	0.61	0.20
Noiser	.95[a] / .91[b]	0.18	0.02	0.18	0.02
LST	.73[a] /.81[b]	0.36	0.17	0.36	0.14
ICT	.83[d]	0.65	0.18	0.64	0.16
LPS7	.83[c] / .61[c]	0.32	0.18	0.28	0.16
IST_FA	.76[a] / .79[b]	0.51	0.20	0.51	0.19
LPS8	.83[c] / .70[c]	0.63	0.31	0.62	0.29
LPS9	.83[c] / .75[c]	0.58	0.15	0.53	0.15
IST_WÜ	.80[a] / .86[b]	0.50	0.19	0.47	0.20
Raven	.93[a] /.94[b]	0.34	0.14	0.32	0.14
Fair	> .78[b] / > .85[c]	0.34	0.07	0.27	0.09
IST_MF	.92[a] / .80[b]	0.54	0.20	0.56	0.24
X-Ray ORT*	> .91[a] / > .78[b]	1.74	0.33	1.85	0.22
PIT	> .87[a] / > .87[b]	6.02	1.68	--	--
CAT	> .88[a] / > .84[b]	--	--	6.58	1.72
BDT1.0	> .80[a] / > .77[b]	3.71	2.49	--	--
BDT2.0	> .88[a] / > .80[b]	--	--	5.50	1.93
TIP	.58 - .90[b]	9.00	1.19	8.12	1.02

Note. [a] internal consistency (Cronbach alpha), [b] split-half reliability, [c] retest reliability, [d] parallel test reliability. Split-half reliability for the LPS tests was calculated for the four subtests together. Split-half reliabilities of TIP data vary depending on the image-library used. Values for the CTB are standardized and detection performance measures of all x-ray screening tests except for the X-Ray ORT have been multiplied with an arbitrary constant due to security reasons. * Reliability measures for the X-Ray ORT were based on test results from novices.

The measurement model with the 2006 sample revealed that all factor loadings on the two constructs ability and detection performance were substantial and significant (see Figure 1). The covariance between ability and detection performance was 0.018 (*SE* = 0.006), $p < .01$, corresponding to a correlation of $r = .38$. According to [16], [17] the model fit was good and should not be rejected $X^2(89, N = 169) = 125.72$, $p < .01$, CFI = .952, RMSEA = .050, AIC = 187.72 (saturated model 240.00), BCC = 194.24 (saturated model 265.26), BIC = 284.74 (saturated model 615.59), CAIC = 315.74 (saturated model 735.59). As indicated by the goodness-of-fit indices, the model for the 2007 sample reproduced the covariance matrix as well very well $X^2(89, N = 97) = 98.99$, $p = .22$, CFI = .981, RMSEA = .036, AIC = 160.99 (saturated model 240.00), BCC = 174.58 (saturated model 292.60), BIC = 238.48 (saturated model 539.98), CAIC = 269.48 (saturated model 659.98). Covariance between the two constructs ability and detection performance was 0.027 (*SE* = 0.007), $p < .01$ and the correlation significant ($r = .57$) respectively (Figure 1). In both

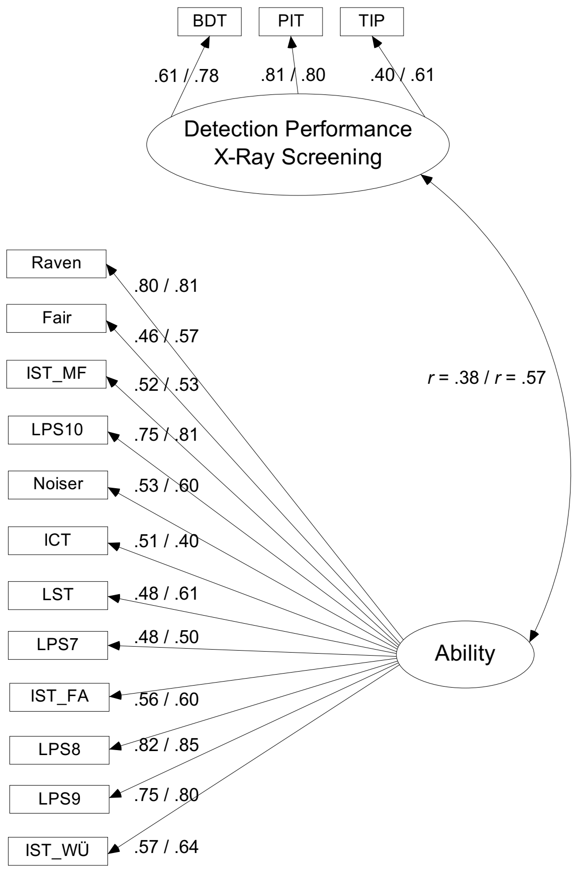

FIGURE 1. Factor model with the two factors ability and detection performance in x-ray screening (circles) and the 15 indicators. For clarity measurement errors are omitted. Standardized loadings are indicated for the 2006 (left) and the 2007 data (right).

models (2006 and 2007) no substantial modifications were required.

To test whether the number of tests can be reduced without losing information, we tested the model with the four indicators Raven, LPS8, LPS9 and LPS10. As can be seen in Figure 1 these tests showed the highest loading on the first order factor ability in both groups. Results evidenced a satisfactory model fit for the 2006 data $X^2(13, N = 169) = 24.38$, $p < .05$, CFI = .971, RMSEA = .072, AIC = 54.38 (saturated model 56.00), BCC = 55.88 (saturated model 58.80), BIC = 101.33 (saturated model 143.64), CAIC = 116.33 (saturated model 171.64) and a very good fit for the 2007 data $X^2(13, N = 97) = 7.38$, $p = .88$, CFI = 1.00, RMSEA = .000, AIC = 37.38 (saturated model 56.00), BCC = 40.34 (saturated model 61.53), BIC = 74.87 (saturated model 126.00), CAIC = 89.87 (saturated model 154.00). By reducing the number of indicators of ability from 12 to 4 indicators, no difference in the substantive results were found, especially in the prediction of the detection performance in x-ray screening.

In order to test what part of the detection performance can be accounted for by the theoretical variables, we performed a

ISBN: 978-0-615-20720-9

full structural equation model analysis, but with the four indicators Raven, LPS8, LPS9 and LPS10 only. Besides the latent variable ability of screeners the test result in the X-Ray ORT is expected to account for a part of the detection performance variability. Again, the SEM was first conducted for the 2006 sample and then for the 2007 data. The model fit indicated with $X^2(17, N = 169) = 27.38$, $p = .05$, CFI = .976, RMSEA = .060, AIC = 65.38 (saturated model 72.00), BCC = 67.53 (saturated model76.08), BIC =124.85 (saturated model 184.68), CAIC = 143.85 (saturated model 220.68) a good fit[1]. Further, results showed a very good model fit for the 2007 sample $X^2(18, N = 97) = 10.82$, $p = .90$, CFI = 1.00, RMSEA = .000, AIC = 46.82 (saturated model 72.00), BCC = 50.87 (saturated model 80.10), BIC = 912.82 (saturated model 161.99), CAIC = 109.82 (saturated model 197.99). Thus, in both groups, ability and the X-Ray ORT display a significant effect on detection performance in x-ray screening.

IV. DISCUSSION

The main goal of this study was to examine which of the 12 general visual cognition tests predict on the job performance best in order to define a reliable and valid pre-employment assessment. Therefore, 12 tests which best match the x-ray screening task were used. To measure on the job performance, test results in the PIT and the BDT as well as TIP data were used. The PIT and BDT are two x-ray screening tests that were part of the recurrent competency assessment. TIP data were measured on the checkpoint and thus on the job performance could be evaluated.

Results revealed that all cognition tests from the visual CTB which are mostly tests from elaborated German intelligence test batteries load on one latent factor ability despite their semantic distinctions. Furthermore, this factor correlates highly with detection performance in x-ray screening for both samples. Reliability of the 2006 sample which was just sufficient may account for the generally worse model fit of the 2006 data compared to the 2007 sample. Our results also suggest that the whole visual CTB which consists of 12 tests can be reduced to four tests without reducing explained variance. Further a full SEM with the X-Ray ORT as additional factor showed that both factors ability and the X-Ray ORT display a significant effect on detection performance. Interestingly, as well the X-Ray ORT which measures the ability to cope with image-based factors in x-ray screening seems to be an important determinant. It has to be considered that the sample used for this study shows relatively small variance as all screeners were already selected based on their ability to cope with image-based factors. Whether ability is even more important is a question that should be answered with a representative sample.

To sum up this study showed that both the ability to cope with image-based factors measured with the X-Ray ORT and the ability measured with the visual CTB play an important role for the x-ray screening task later on the job. The positive relationship between the X-Ray ORT and detection performance later on the job could also be shown in a previous study by [3]. Thus, the X-Ray ORT as well as the visual CTB can be used within a pre-employment assessment. However, to increase efficiency a reduction of the visual CTB from 12 to 4 tests only should be taken into consideration.

Further analysis should investigate whether other factors relevant for the x-ray screening job could be subjected to SEM, such as training hours, age, personality traits etc. According [20] as well as [18] it could be expected that training hours influence detection performance on the job remarkably. Further studies investigating the effect of age on x-ray screening showed as well a significantly worse detection performance of older screeners compared to younger ones despite their working experience [19].

[1] The TIP data for the 2006 sample showed the lowest factor loadings. Nevertheless we tried to integrate this indicator because of his importance to the latent variable detection performance in x-ray screening.

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ACKNOWLEDGMENT

This research was financially supported by the European Commission Leonardo da Vinci Programme (VIA Project, DE/06/C/F/TH-80403). Thanks to Zurich State Police, Airport Division for supporting this study by supplying screeners and data.

APPENDIX

TABLE II. CORRELATION MATRIX OF INDICATORS FOR 2006 SAMPLE

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. ORT	---														
2. LST	.20	----													
3. Noiser	.11	.36	---												
4. LPS10	.15	.35	.45	---											
5. IST_MF	.16	.18	.47	.41	---										
6. Raven	.09	.36	.37	.64	.38	---									
7. Fair	.14	.16	.30	.31	.38	.36	---								
8. LPS9	.05	.33	.33	.62	.34	.60	.36	---							
9. IST_WÜ	.10	.24	.27	.33	.27	.52	.32	.40	---						
10. IST_FA	.05	.36	.26	.41	.25	.43	.18	.47	.41	---					
11. LPS8	.10	.39	.42	.59	.44	.66	.40	.64	.49	.44	---				
12. ICT	.11	.30	.30	.38	.26	.44	.20	.37	.27	.17	.45	---			
13. LPS7	.08	.21	.23	.38	.22	.43	.18	.34	.29	.33	.36	.22	---		
14. TIP	-.17	.09	.14	.19	.16	.28	.21	.26	.12	.15	.21	.13	.20	---	
15. PIT	.30	.34	.20	.19	.17	.13	.09	.19	.08	.18	.21	.12	.18	.34	---
16. BDT1.0	.35	.26	.19	.15	.15	.23	.16	.13	.18	.25	.18	.14	.21	.15	.50

TABLE III. CORRELATION MATRIX OF INDICATORS FOR 2007 SAMPLE

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. ORT	---														
2. LST	.23	---													
3. Noiser	.17	.39	---												
4. LPS10	.18	.51	.50	---											
5. IST_MF	.12	.39	.35	.40	---										
6. Raven	.15	.45	.52	.65	.44	---									
7. Fair	.12	.32	.27	.51	.44	.53	---								
8. LPS9	.24	.54	.48	.64	.44	.69	.43	---							
9. IST_WÜ	.17	.25	.29	.49	.26	.54	.31	.52	---						
10. IST_FA	.10	.39	.34	.45	.37	.44	.39	.47	.42	---					
11. LPS8	.27	.54	.50	.70	.39	.67	.45	.65	.64	.54	---				
12. ICT	-.00	.27	.36	.30	.32	.23	.21	.30	.24	.29	.39	---			
13. LPS7	.33	.26	.35	.42	.28	.40	.27	.39	.31	.27	.43	.11	---		
14. TIP	.07	-.05	.13	.30	.07	.33	.25	.26	.24	.12	.26	-.03	.35	---	
15. CAT	.19	.26	.37	.40	.16	.36	.14	.39	.24	.20	.38	.32	.38	.50	---
16. BDT2.0	.13	.29	.26	.34	.23	.40	.21	.33	.35	.22	.42	.10	.33	.48	.62

ISBN: 978-0-615-20720-9