Supplemental Material: Open Set Fingerprint Spoof Detection Across Novel Fabrication Materials

I. EXPERIMENT #1: DET CURVES

Performance of the spoof detector on previously known and novel materials; full DET curves for the LBP + Biometrika combination in Table II from the article:
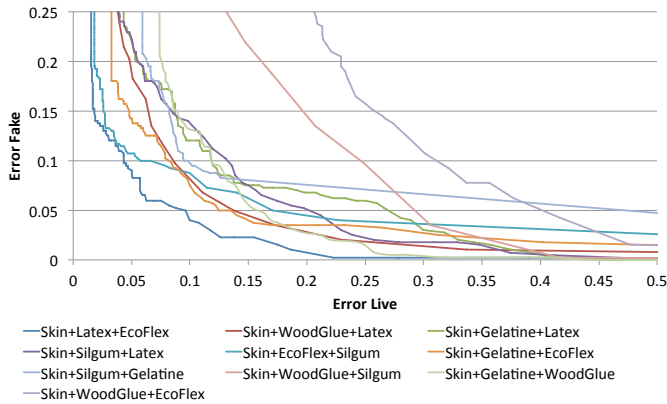

Fig. 1. Combination Biometrika + LBP, all performance points when testing the spoof detector on previously known materials.
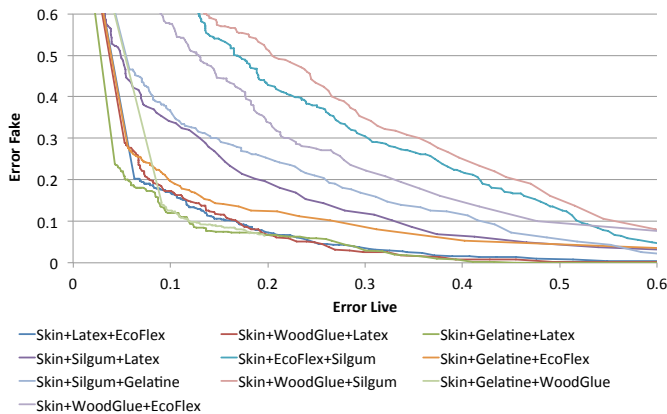

Fig. 2. Combination Biometrika + LBP, all performance points when testing the spoof detector on novel materials. Notice that the curves shift to the right, compared to Fig. 1, indicating degraded performance.

II. EXPERIMENT #3: ADDITIONAL DET CURVES

Performance of the spoof detector re-trained on samples flagged by the novel material detector; full DET curves for the LBP + Biometrika combination in Table IV from the article:

Fig. 3. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_2 without adaption.

Fig. 4. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_2, after adaption with detected novel materials from T_1. Notice that the curves shift to the left, compared to Fig. 3, indicating improved performance.

III. EXPERIMENT #4: DET CURVES

Performance of the spoof detector re-trained using ground-truth (oracle test); full DET curves for the LBP + Biometrika combination in Table VIII from the article:
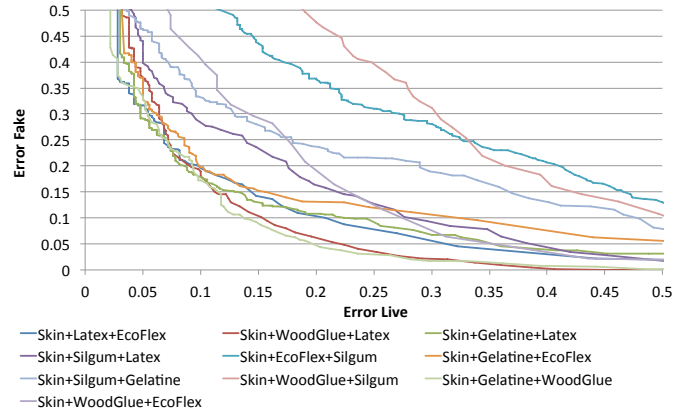

Fig. 5. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_1 without adaption.

Fig. 7. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_1, after adaption with all spoofs from T_2.
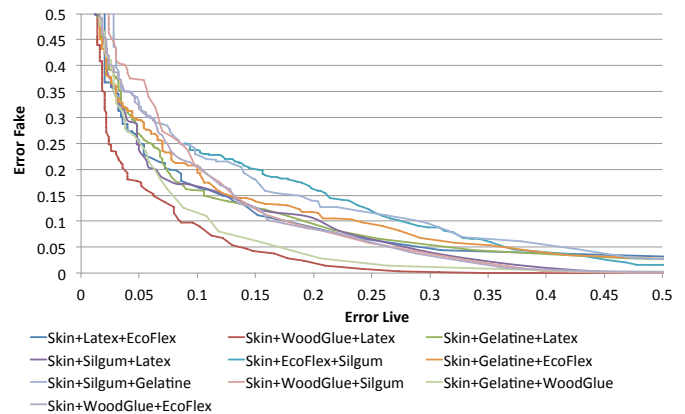

Fig. 6. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_1, after adaption with detected novel materials from T_2. Notice that the curves shift to the left, compared to Fig. 5, indicating improved performance.
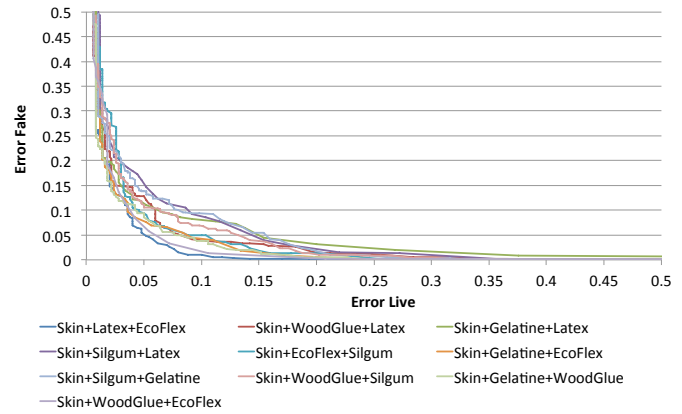

Fig. 8. Combination Biometrika + LBP, all performance points when testing the spoof detector on set T_2, after adaption with all spoofs from T_1.
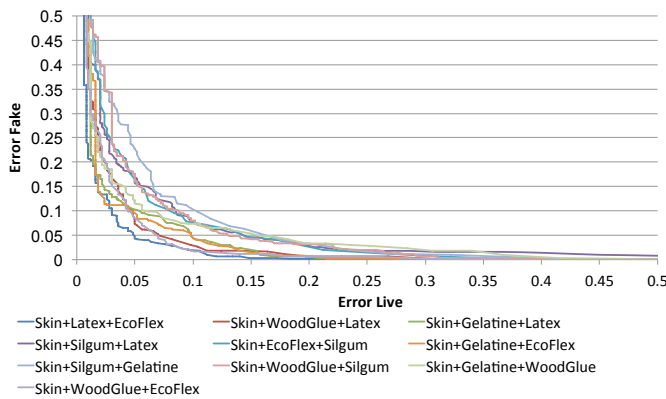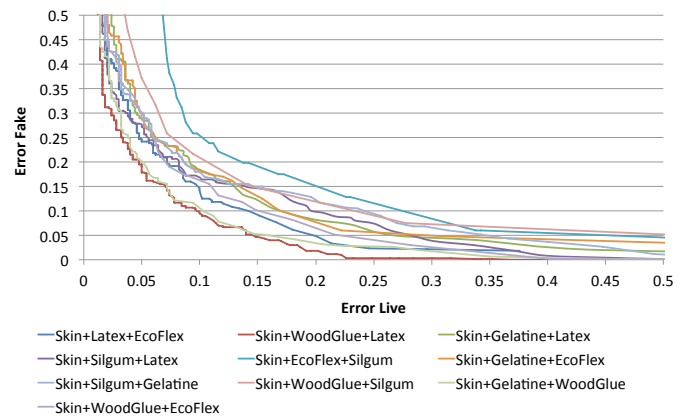
IV. EXPERIMENT #4: COMPLETE TABLES

Performance of the liveness detector retrained using ground-truth (oracle test); complete tables showing data that were used to create summary Table VIII in the article:

TABLE I

EER OF THE **Biometrika**-BASED LIVENESS DETECTOR RETRAINED USING THE GROUND-TRUTH ($\mathcal{L}^{LBP'}, \mathcal{L}^{LPQ'}, \mathcal{L}^{BSIF'}$), *i.e.*, RETRAINED USING ALL OF THE SAMPLES IN T_1 AND EVALUATED ON T_2. CROSS-VALIDATION IS PERFORMED BY INTERCHANGING THE ROLE OF T_1 AND T_2. COMPARATIVE ASSESSMENT HAS BEEN MADE WITH THE LIVENESS DETECTOR THAT IS NOT AUTOMATICALLY RETRAINED ($\mathcal{L}^{LBP}, \mathcal{L}^{LPQ}, \mathcal{L}^{BSIF}$).

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_1) [%]	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	14.6	12.2	7.0	6.2
Skin+WoodGlue+Latex	12.8	10.5	9.8	8.1
Skin+Gelatine+Latex	13.8	14.2	10.2	8.3
Skin+Silgum+Latex	18.2	15.0	14.2	9.2
Skin+EcoFlex+Silgum	29.6	16.8	21.0	7.4
Skin+Gelatine+EcoFlex	15.2	14.6	10.4	6.5
Skin+Silgum+Gelatine	22.2	14.5	18.2	9.4
Skin+WoodGlue+Silgum	30.4	14.2	27.2	8.4
Skin+Gelatine+WoodGlue	12.2	10.7	10.0	7.4
Skin+WoodGlue+EcoFlex	19.8	11.8	12.2	5.6
Average EER:	18.9 ± 2.1	$\mathbf{13.5 \pm 0.6}$	14.0 ± 2.0	$\mathbf{7.7 \pm 0.4}$
Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_1) [%]	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	19.8	13.6	9.4	7.4
Skin+WoodGlue+Latex	21.6	12.0	9.8	8.0
Skin+Gelatine+Latex	18.6	16.2	10.0	8.8
Skin+Silgum+Latex	18.2	13.8	10.8	8.6
Skin+EcoFlex+Silgum	22.6	15.2	16.2	11.0
Skin+Gelatine+EcoFlex	22.4	16.8	14.2	10.6
Skin+Silgum+Gelatine	20.4	15.8	13.8	10.6
Skin+WoodGlue+Silgum	19.2	12.8	13.6	8.0
Skin+Gelatine+WoodGlue	18.6	14.8	14.0	10.4
Skin+WoodGlue+EcoFlex	22.0	15.0	13.0	6.6
Average EER:	20.3 ± 0.5	$\mathbf{14.6 \pm 0.5}$	12.5 ± 0.7	$\mathbf{9.0 \pm 0.5}$
Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_1) [%]	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	15.8	12.4	7.8	4.8
Skin+WoodGlue+Latex	17.4	13.8	11.2	5.8
Skin+Gelatine+Latex	18.4	13.6	9.4	6.0
Skin+Silgum+Latex	21.4	15.4	11.8	6.4
Skin+EcoFlex+Silgum	28.2	17.4	16.2	8.8
Skin+Gelatine+EcoFlex	24.0	16.6	16.0	7.4
Skin+Silgum+Gelatine	25.2	17.8	15.6	8.6
Skin+WoodGlue+Silgum	25.0	17.6	16.0	7.8
Skin+Gelatine+WoodGlue	19.4	14.6	13.8	7.0
Skin+WoodGlue+EcoFlex	19.8	15.0	13.0	7.0
Average EER:	21.5 ± 1.3	$\mathbf{15.4 \pm 0.6}$	13.1 ± 0.9	$\mathbf{7.0 \pm 0.4}$

TABLE II

EER OF THE **Italdata**-BASED LIVENESS DETECTORS RETRAINED USING THE GROUND-TRUTH ($\mathcal{L}^{LBP'}, \mathcal{L}^{LPQ'}, \mathcal{L}^{BSIF'}$), *i.e.*, RETRAINED USING ALL OF THE SAMPLES IN T_1 AND EVALUATED ON T_2. CROSS-VALIDATION IS PERFORMED BY INTERCHANGING THE ROLE OF T_1 AND T_2. COMPARATIVE ASSESSMENT HAS BEEN MADE WITH THE LIVENESS DETECTOR THAT IS NOT AUTOMATICALLY RETRAINED ($\mathcal{L}^{LBP}, \mathcal{L}^{LPQ}, \mathcal{L}^{BSIF}$).

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_1) [%]	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	30.3	25.2	26.9	19.2
Skin+WoodGlue+Latex	21.2	22.8	19.7	17.2
Skin+Gelatine+Latex	27.8	23.6	25.3	17.2
Skin+Silgum+Latex	28.8	23.4	26.5	18.2
Skin+EcoFlex+Silgum	31.9	24.8	30.0	18.8
Skin+Gelatine+EcoFlex	37.3	26.4	35.1	23.6
Skin+Silgum+Gelatine	32.2	25.4	29.4	18.6
Skin+WoodGlue+Silgum	36.0	26.2	33.4	22.4
Skin+Gelatine+WoodGlue	27.1	23.6	25.8	16.6
Skin+WoodGlue+EcoFlex	29.0	24.4	31.0	17.4
Average EER:	30.2 ± 1.5	$\mathbf{24.6 \pm 0.4}$	28.3 ± 1.4	$\mathbf{18.9 \pm 0.7}$
Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_1) [%]	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	21.5	17.2	17.5	16.8
Skin+WoodGlue+Latex	20.6	17.2	20.4	14.0
Skin+Gelatine+Latex	18.6	16.8	14.9	13.4
Skin+Silgum+Latex	24.0	14.2	20.8	14.6
Skin+EcoFlex+Silgum	30.3	24.2	25.0	17.6
Skin+Gelatine+EcoFlex	26.9	20.6	20.3	18.6
Skin+Silgum+Gelatine	22.3	16.0	16.8	14.8
Skin+WoodGlue+Silgum	23.2	17.6	21.7	14.6
Skin+Gelatine+WoodGlue	23.9	15.2	21.1	15.2
Skin+WoodGlue+EcoFlex	24.4	16.6	22.0	18.2
Average EER:	23.6 ± 1.0	$\mathbf{17.6 \pm 0.9}$	20.1 ± 0.9	$\mathbf{15.8 \pm 0.6}$
Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_1) [%]	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_2) [%]
Skin+Latex+EcoFlex	33.7	27.2	26.3	19.8
Skin+WoodGlue+Latex	23.4	24.2	23.3	27.6
Skin+Gelatine+Latex	26.9	23.6	22.2	22.2
Skin+Silgum+Latex	27.8	26.0	27.7	26.2
Skin+EcoFlex+Silgum	37.1	28.0	32.9	23.8
Skin+Gelatine+EcoFlex	39.7	29.6	33.7	26.2
Skin+Silgum+Gelatine	34.6	27.8	28.9	25.0
Skin+WoodGlue+Silgum	35.0	28.8	34.7	28.4
Skin+Gelatine+WoodGlue	28.1	26.6	23.9	24.0
Skin+WoodGlue+EcoFlex	29.0	25.0	27.6	19.6
Average EER:	31.5 ± 1.6	$\mathbf{26.7 \pm 0.6}$	28.1 ± 1.4	$\mathbf{24.3 \pm 1.0}$

TABLE III
EER OF THE **DigitalPersona**-BASED LIVENESS DETECTORS RETRAINED USING THE GROUND-TRUTH ($\mathcal{L}^{LBP'}, \mathcal{L}^{LPQ'}, \mathcal{L}^{BSIF'}$), *i.e.*, RETRAINED USING ALL OF THE SAMPLES IN T_1 AND EVALUATED ON T_2. CROSS-VALIDATION IS PERFORMED BY INTERCHANGING THE ROLE OF T_1 AND T_2. COMPARATIVE ASSESSMENT HAS BEEN MADE WITH THE LIVENESS DETECTOR THAT IS NOT AUTOMATICALLY RETRAINED ($\mathcal{L}^{LBP}, \mathcal{L}^{LPQ}, \mathcal{L}^{BSIF}$).

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_1) [%]	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	38.9	23.8	32.4	19.4
Skin+WoodGlue+Latex	37.7	20.0	39.1	21.8
Skin+Gelatine+Latex	34.2	19.0	42.9	30.0
Skin+Silicone+Latex	44.0	22.6	47.5	27.4
Skin+Playdoh+Silicone	39.6	25.6	36.5	20.2
Skin+Gelatine+Playdoh	27.4	21.0	30.9	22.4
Skin+Silicone+Gelatine	38.0	20.0	48.7	31.6
Skin+WoodGlue+Silicone	38.3	22.8	40.4	20.2
Skin+Gelatine+WoodGlue	28.8	19.4	36.8	23.8
Skin+Playdoh+WoodGlue	36.9	27.2	30.9	19.0
Average EER:	36.4 ± 1.7	**22.1 ± 0.9**	38.6 ± 2.1	**23.6 ± 1.5**

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_1) [%]	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	44.1	16.0	43.8	10.4
Skin+WoodGlue+Latex	42.9	13.4	37.1	9.2
Skin+Gelatine+Latex	33.2	15.0	32.4	10.6
Skin+Silicone+Latex	42.6	14.0	36.0	8.0
Skin+Playdoh+Silicone	27.1	15.6	26.3	9.4
Skin+Gelatine+Playdoh	50.1	15.2	54.0	10.0
Skin+Silicone+Gelatine	38.5	15.2	44.5	10.0
Skin+WoodGlue+Silicone	47.8	15.0	42.4	7.4
Skin+Gelatine+WoodGlue	38.8	14.8	37.8	8.2
Skin+Playdoh+WoodGlue	32.5	13.6	25.4	8.4
Average EER:	39.8 ± 2.3	**14.8 ± 0.3**	38.0 ± 2.8	**9.2 ± 0.3**

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_1) [%]	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	26.4	20.8	22.7	16.8
Skin+WoodGlue+Latex	36.9	21.6	32.6	17.4
Skin+Gelatine+Latex	21.9	21.6	21.5	18.4
Skin+Silicone+Latex	29.5	21.0	23.5	17.8
Skin+Playdoh+Silicone	24.6	21.0	21.0	17.8
Skin+Gelatine+Playdoh	29.3	21.4	30.0	19.8
Skin+Silicone+Gelatine	26.1	21.0	27.5	18.8
Skin+WoodGlue+Silicone	27.7	20.2	21.8	18.2
Skin+Gelatine+WoodGlue	21.8	22.6	21.6	18.4
Skin+Playdoh+WoodGlue	23.0	20.6	19.3	17.8
Average EER:	26.7 ± 1.4	**21.2 ± 0.2**	24.2 ± 1.4	**18.1 ± 0.3**

TABLE IV
EER OF THE **Sagem**-BASED LIVENESS DETECTORS RETRAINED USING GROUND-TRUTH ($\mathcal{L}^{LBP'}, \mathcal{L}^{LPQ'}, \mathcal{L}^{BSIF'}$), *i.e.*, RETRAINED USING ALL OF THE SAMPLES IN T_1 AND EVALUATED ON T_2. CROSS-VALIDATION IS PERFORMED BY INTERCHANGING THE ROLE OF T_1 AND T_2. COMPARATIVE ASSESSMENT HAS BEEN MADE WITH THE LIVENESS DETECTOR THAT IS NOT AUTOMATICALLY RETRAINED ($\mathcal{L}^{LBP}, \mathcal{L}^{LPQ}, \mathcal{L}^{BSIF}$).

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_1) [%]	$\mathcal{L}^{LBP}$ (not adapted) [%]	$\mathcal{L}^{LBP'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	21.8	15.0	18.0	14.4
Skin+WoodGlue+Latex	30.6	14.8	23.1	13.6
Skin+Gelatine+Latex	14.8	12.6	15.8	14.4
Skin+Silicone+Latex	26.7	14.4	22.7	14.2
Skin+Playdoh+Silicone	28.6	17.0	21.1	15.4
Skin+Gelatine+Playdoh	21.9	14.4	30.2	14.8
Skin+Silicone+Gelatine	14.5	13.0	19.3	16.0
Skin+WoodGlue+Silicone	31.4	16.2	25.4	14.6
Skin+Gelatine+WoodGlue	13.9	12.4	15.6	14.8
Skin+Playdoh+WoodGlue	21.9	15.8	18.5	16.2
Average EER:	22.6 ± 2.2	**14.6 ± 0.5**	21.0 ± 1.5	**14.8 ± 0.3**

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_1) [%]	$\mathcal{L}^{LPQ}$ (not adapted) [%]	$\mathcal{L}^{LPQ'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	17.9	13.8	20.2	17.8
Skin+WoodGlue+Latex	39.2	16.4	30.6	13.8
Skin+Gelatine+Latex	19.2	10.8	16.6	14.2
Skin+Silicone+Latex	28.0	16.4	21.8	14.8
Skin+Playdoh+Silicone	34.3	15.8	35.7	17.6
Skin+Gelatine+Playdoh	32.3	12.4	36.1	19.0
Skin+Silicone+Gelatine	34.0	13.4	31.4	14.6
Skin+WoodGlue+Silicone	28.9	18.4	22.5	15.0
Skin+Gelatine+WoodGlue	20.9	13.0	19.6	14.4
Skin+Playdoh+WoodGlue	17.8	16.0	19.3	18.2
Average EER:	27.3 ± 2.5	**14.6 ± 0.7**	25.4 ± 2.3	**15.9 ± 0.6**

Training materials	Tested on T_2		Tested on T_1	
	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_1) [%]	$\mathcal{L}^{BSIF}$ (not adapted) [%]	$\mathcal{L}^{BSIF'}$ (adapted using T_2) [%]
Skin+Latex+Playdoh	20.7	14.0	21.4	19.8
Skin+WoodGlue+Latex	46.6	14.4	39.4	18.6
Skin+Gelatine+Latex	18.5	12.4	22.3	20.0
Skin+Silicone+Latex	24.7	15.8	22.7	16.0
Skin+Playdoh+Silicone	25.0	17.4	29.6	17.2
Skin+Gelatine+Playdoh	23.6	15.0	35.0	19.2
Skin+Silicone+Gelatine	21.8	14.6	26.3	16.4
Skin+WoodGlue+Silicone	23.2	15.4	20.4	16.6
Skin+Gelatine+WoodGlue	18.2	13.8	25.8	20.6
Skin+Playdoh+WoodGlue	19.5	14.6	23.9	20.2
Average EER:	24.2 ± 2.6	**14.7 ± 0.4**	26.7 ± 2.0	**18.5 ± 0.6**