Emotions through the eyes of our closest living relatives: exploring attentional and behavioral mechanisms

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Appendices

Appendix A

Supplementary Materials for Chapter 2

Experiment 1: Bonobos' attentional bias towards emotions of familiar and unfamiliar conspecifics.

Table S1. Definition of emotion categories used for bonobos in Experiment 1, and number of pictures per emotion category and per familiarity category.

Picture category	Description	No. of individuals per picture	No. of unfamiliar pictures	No. of familiar pictures
Distress	Aggressive displays (e.g., charges and direct displays); submissive behaviors (e.g., grin faces, fleeing and crouching)	$M = 1.55$, $SE = 0.16$	15	25
Sex	Mating, genito-genital rubbing, prominent full swelling, penile erection	$M = 2.25$, $SE = 0.25$	27	16
Playing	Together or alone, with a relaxed open mouth, without an object	$M = 2.25$, $SE = 0.25$	22	36
Grooming	Two or more individuals grooming	$M = 2.38$, $SE = 0.26$	53	50
Yawning	Wide-open mouth with or without teeth exposure	$M = 1.17$, $SE = 0.17$	20	16
Self-scratching	Roughly rubbing the body, face, or one of the limbs	$M = 1.00$, $SE = 0.00$	18	30
Neutral	Walking, lying down, or sitting	$M = 1.67$, $SE = 0.14$	155	173

Note. All bonobo participants saw the same number of unique pictures, but for the familiar models the composition of the stimulus set differed per participant because we replaced pictures of the participants themselves with pictures of other familiar individuals. Furthermore, the number of pictures differs per *Familiarity* and also per *Picture category* because some behaviours were easier to photograph or occurred more frequently than other behaviours.

Appendix to stimuli and validation

Six primate experts scored the pictures of bonobos based on valence and intensity. Three experts worked with the bonobos on a daily basis, and the others worked with bonobos or chimpanzees in the past. Experts were presented with one picture at a time and were asked to 1) rate how negative or positive they thought bonobos would experience each picture (1= very negative, 7 = very positive) and 2) how intense the picture was (1= not intense, 7 = very intense). Pictures were shown until a response was given. We calculated intraclass correlations (ICCs) for valence and intensity ratings using a two-way mixed model and a consistency definition and found a high reliability for both ratings ($ICC_{valence} = .82$, 95% CI: .79 - .84, $F(653, 3265) = 5.45$, $p < .001$; $ICC_{intensity} = .87$, 95% CI: .86-.89, $F(653, 3265) = 7.96$, $p < .001$). A generalized linear

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mixed model with *Emotionality* (emotion versus neutral) as fixed factor, *Rating* as target variable and *Rater Number* as random effect confirmed that emotional pictures are indeed rated higher in intensity than neutral pictures ($M_{emotional}$ = 3.28, *SE* = 0.35, $M_{neutral}$ = 1.76, *SE* = 0.18, *F*(1, 3922) = 1337.81, *p* < .001).

Table S2. Overview of average intensity and valence ratings per emotion category and per familiarity category in Experiment 1.

	Familiar		Unfamiliar	
Emotion category	Average Valence (SD)	Average Intensity (SD)	Average Valence (SD)	Average Intensity (SD)
Distress	3.07 (1.38)	4.73 (1.57)	3.49 (1.55)	4.74 (1.39)
Sex	5.93 (0.85)	4.90 (1.28)	5.88 (0.93)	4.94 (1.34)
Play	5.31 (0.95)	3.12 (1.58)	5.44 (0.92)	2.89 (1.44)
Groom	5.31 (0.82)	3.09 (1.64)	5.15 (0.83)	2.73 (1.57)
Yawn	3.96 (0.92)	3.31 (1.56)	3.97 (1.00)	3.53 (1.62)
Self-scratch	4.11 (1.07)	1.76 (0.71)	4.14 (1.02)	1.74 (0.78)
Neutral	4.63 (0.91)	1.64 (0.89)	4.62 (0.88)	1.74 (0.98)

Table S3. Number of incorrect trials per bonobo in Experiment 1.

Participant name	Tested trials (sessions)	Repetitions of trials*	Incorrect trials (% of grand total) †	Of which due to nose wipes	Of which due to self-scratching	Of which due to outliers‡
Besede	525 (21)	202	130 (6.0 %)	2	1	127
Kumbuka	582 (24)	264	181 (8.4%)	38	2	141
Monyama	537 (22)	212	104 (4.8%)	2	0	102
Yahimba	518 (21)	210	99 (4.6%)	4	0	95
Grand total	2162	888	514 (23.8 %)	46	3	465

* These reflect the number of trials that were repeated due to disruptions in the first/original trials.

† The number of incorrect trials consists of both erroneous trials within the first/original trials and erroneous trials within the repetitions.

‡ Outliers were disruptions during a trial other than due to the behaviours described above, e.g.: not attending to the screen during stimulus presentation, someone other than the participant pressing the probe, using the opposing hand, not sitting directly in front of the screen, or the screen not immediately responding to a touch. Outliers also contain extreme RTs (250 < RT < 5000) and RTs higher than the median RT per participant minus 2.5*MAD per participant.

Appendix to results

Table S4.1. Individual and overall reaction time means and standard deviations per condition in Experiment 1

Individuals	Familiar		Unfamiliar	
	Congruent *M (SD)*	Incongruent *M (SD)*	Congruent *M (SD)*	Incongruent *M (SD)*
Besede	699.73 (95.78)	702.63 (101.11)	697.43 (88.19)	714.96 (87.84)
Kumbuka	534.77 (64.87)	535.84 (69.44)	518.17 (75.58)	532.12 (68.29)
Monyama	460.44 (75.00)	449.59 (71.63)	456.89 (76.93)	473.03 (58.25)
Yahimba	431.61 (66.60)	421.19 (62.18)	422.49 (66.89)	423.12 (71.12)

Table S4.2. Model output from Experiment 1.

Predictors	β	*SE*	*t*	*p*
(Intercept)	532.16	55.31	9.62	.001***
Congruency (*congruent)*	-1.47	1.85	-.80	.426
Familiarity (*familiar*)	-.11	1.85	.06	.952
Congruency* Familiarity	3.77	1.85	2.04	.042*
Random effects	*Variance*	*SD*		
Session*ID (intercept)	264.2	16.25		
ID (intercept)	12090.4	109.95		
Residual	5597.4	74.82		

Number of observations: 1648, Session*ID: 8, ID:4. Note that by sum coding, the levels of all factors have been mean centred. As such, the intercept reflects the grand mean of all predictors.

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Experiment 2: Bonobos' attentional bias towards emotions of familiar and unfamiliar humans.

Table S5.1. Overview of average agreement on emotionality (emotional/neutral), average rating scores for emotional intensity and authenticity rated by N=5 research assistants in Experiment 2.

	Caretaker (familiar)			NimStim (unfamiliar)		
Stimulus category	Agreement on emotionality (SD)	Intensity rating (SD)	Authenticity rating (SD)	Agreement on emotionality (SD)	Intensity rating (SD)	Authenticity rating (SD)
Emotional	92.8% (.26)	4.21 (1.36)	4.37 (1.60)	88.9% (.32)	5.09 (1.34)	3.66 (1.56)
Neutral	77.3% (.42)	2.84 (1.67)	5.04 (1.32)	100% (.00)	3.18 (1.58)	4.80 (1.39)

Note. Agreement on emotion refers to the average agreement between 5 raters on whether emotional stimuli were recognized as an emotion by them, and neutral stimuli as neutral. Agreement on whether a stimulus was emotional or neutral was not 100% on average, meaning raters sometimes rated a neutral expression as emotional and vice versa. Furthermore, low intensity scores for neutral stimuli and high intensity scores for emotional stimuli are preferred, because this means there is a clear discrepancy between two simultaneously presented stimuli and as such, highly intense (emotional) stimuli can capture attention faster than low-intensity (neutral) stimuli. A generalized linear mixed model with *Emotionality* (emotion versus neutral) as fixed factor, *Rating* as target variable and *Rater Number* as random effect confirmed that emotional pictures are indeed rated higher in intensity than neutral pictures ($M_{emotional} = 4.70$, $SE = 0.39$, $M_{neutral} = 2.79$, $SE = 0.24$, $F(1, 603) = 233.19$, $p < .001$).

Table S5.2. ICCs of scores on the different scales (intensity, emotionality (emotion/neutral), and authenticity using two-way mixed effects using a consistency definition in Experiment 2 (N=6).

Scale	Intraclass Correlation	95% confidence interval		*F* value (df1, df2)	*P* value
Intensity	.78	.71	.84	4.53 (120, 480)	.000
Emotion	.66	.55	.75	2.94 (120, 480)	.000
Authenticity	.69	.59	.77	3.20 (120, 480)	.000

Table S6. Number of incorrect trials per bonobo on the dot-probe with human stimuli Experiment 2.

Participant name	Tested trials (sessions)	Repetitions of trials*	Incorrect trials (% of grand total) †	Of which due to nose wipes	Of which due to self-scratching	Of which due to outliers‡
Besede	325 (13)	198	66 (20.3)	0	0	58
Kumbuka	326 (13)	198	106 (32.5)	15	0	73
Monyama	377 (15)	245	78 (20.7)	0	0	48
Yahimba	350 (14)	223	123 (35.1)	1	0	58
Grand total	1378	864	373	16	0	237

* These reflect the number of trials that were repeated due to disruptions in the first/original trials.

† The number of incorrect trials consists of both erroneous trials within the first/original trials and erroneous trials within the repetitions.

‡ Outliers were disruptions during a trial other than due to the behaviours described above, e.g.: not attending the screen during stimulus presentation, someone other than the participant pressing the probe, using the opposing hand, not sitting directly in front of the screen, or the screen not immediately responding to a touch. Outliers also contain extreme RTs (250 < RT < 5000) and RTs higher than the median RT per participant minus 2.5*MAD per participant.

Appendix to results

Table S7.1. Individual and overall reaction time means and standard deviations per condition

Individuals	Familiar (Caretaker)		Unfamiliar (NimStim)	
	Congruent *M (SD)*	Incongruent *M (SD)*	Congruent *M (SD)*	Incongruent *M (SD)*
Besede	628.21 (125.55)	631.84 (133.57)	630.15 (113.73)	635.15 (113.28)
Kumbuka	526.69 (52.74)	530.69 (49.84)	525.93 (61.46)	526.43 (52.41)
Monyama	429.28 (62.39)	430.03 (69.86)	437.04 (73.85)	438.94 (66.04)
Yahimba	399.79 (56.26)	400.79 (76.19)	379.63 (84.67)	394.47 (76.73)

Table S7.2. Model output from Experiment 2.

Predictors	β	*SE*	*t*	*P*
(Intercept)	491.33	41.69	11.79	.001***
Congruency (*congruent)*	-1.44	2.51	-.58	.565
Familiarity (*unfamiliar/familiar*)	-.50	2.50	-.20	.842
Congruency* Familiarity	.99	2.50	.40	.691
Random effects	*Variance*	*SD*		
Session*ID (intercept)	1818	42.64		
ID (intercept)	6315	79.46		
Residual	6275	79.21		

Number of observations: 1005, Session*ID: 12, ID:4. Note that by sum coding, the levels of all factors have been mean centred. As such, the intercept reflects the grand mean of all predictors.

Table S8. Model output from the control experiment as part of Experiment 2.

Predictors	β	*SE*	*t*	*p*
(Intercept)	6.08	.009	665.1	< .001***
Congruency (*congruent)*	-.003	.002	-2.00	.046*
Familiarity (*unfamiliar*)	.000	.002	-.10	.931
Congruency* Familiarity	-.001	.002	.20	.867
Random effects	*Variance*	*SD*		
ID (intercept)	.00	.06		
Residual	.03	.16		

Number of observations: 9788, ID: 150. Note that results are given on the log (not the response) scale. For clarity, 3 decimals are reported for the beta estimate and standard error. By sum coding, the levels of all factors have been mean centred. As such, the intercept reflects the grand mean of all predictors.

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Experiment 3: Humans' attentional bias towards emotions of familiar and unfamiliar conspecifics.

Appendix to participants

Table S9. Descriptives of participants and their relation to the participant on the stimuli in Experiment 3.

Relationship participant on task versus participant on photo*	Sex participant on task versus Sex participant on photos				
	Male versus Male	Male versus Female	Female versus Female	Female versus Male	Grand total
Brother/sister	25	25	32	19	101
Child	25	16	33	23	97
Parent	22	23	25	28	98
Spouse/partner	1	27	0	48	76
Niece/nephew[†]	0	1	1	0	2
Friend/Colleague	8	3	12	7	30
Grand total	81	95	103	125	404[‡]

* The relationship is seen from the viewpoint of the participant doing the task, e.g., "Child" means that the stimuli are of the child of the participant who performed the dot probe task.

[†] As we were interested in how closely bonded individuals attend to each other's emotions, we focused mainly on families and friends. We did not collect a lot of participants with a more distant family relationship (e.g., aunts/uncles, nephews/nieces, cousins), but decided not to remove the 2 participants with a niece or nephew.

[‡] Note that this number is not the same as the one reported in the main text (N=449), this is because of a technical failure, the relationship data of 45 participants was not registered.

Appendix to stimulus validation

Table S10.1. Overview of average agreement on emotionality (emotion/neutral), and average rating scores for emotional intensity and authenticity of human stimuli in Experiment 2.

Rater group	Neutral stimuli			Emotional stimuli		
	Agreement on emotionality (SD)	Intensity rating (SD)	Authenticity rating (SD)	Agreement on emotionality (SD)	Intensity rating (SD)	Authenticity rating (SD)
1	82.9% (.38)	3.16 (1.85)	5.72 (2.41)	68.3% (.47)	4.08 (1.86)	4.85 (1.87)
2	74.8% (.43)	2.17 (1.64)	5.79 (1.42)	88.3% (.32)	4.97 (1.79)	5.39 (1.65)
3	77.3% (.42)	2.69 (1.3)	5.26 (1.66)	90.5% (.29)	4.44 (1.59)	4.06 (1.88)
Grand average	81.5% (.39)	2.99 (1.83)	5.71 (1.29)	70.9% (.45)	4.18 (1.71)	5.29 (1.43)

Note. Rater group 1, N = 8; Group 2, N = 5; Group 3, N = 5. Agreement on emotion/neutral refers to the average agreement between raters on whether emotional stimuli were recognized as an emotion by them, and neutral stimuli as neutral. Agreement was not 100% on average, meaning raters sometimes rated an emotional expression as neutral and vice versa. Intensity and authenticity were rated on a scale from 1-7 (1 = low intensity/ authenticity, 7 = high intensity/authenticity). Furthermore, low intensity scores for neutral stimuli and high intensity scores for emotional stimuli are preferred, because this means there is a clear discrepancy between two simultaneously presented stimuli and as such, highly intense (emotional) stimuli can capture attention faster than low-intensity (neutral) stimuli. A generalized linear mixed model with *Emotionality* (emotion versus neutral) as fixed factor, *Rating* as target variable and *Rater Group*Rater Number* as random effect confirmed that emotional pictures are indeed rated higher in intensity than neutral pictures ($M_{emotional} = 4.17$, $SE = 0.22$, $M_{neutral} = 2.74$, $SE = 0.14$, $F(1, 30377) = 5139.47$, $p < .001$).

Table S10.2. ICC (two-way mixed, consistency) on intensity scores, emotion type, and authenticity scores per rater group in Experiment 2.

	Rater group	Intraclass Correlation	95% confidence interval		F value (df1, df2)	*p* value
Intensity scores	1	.74	.73	.76	3.90 (3078, 21546)	.000
	2	.89	.88	.91	9.34 (568, 2748)	.000
	3	.78	.74	.82	4.63 (263, 1052)	.000
Emotion type scores	1	.92	.91	.92	12.07 (3219, 22533)	.000
	2	.69	.65	.72	3.18 (687, 2748)	.000
	3	.82	.78	.85	5.49 (263, 1052)	.000
Authenticity	1	.70	.68	.71	3.29 (3078, 21546)	.000
	2	.60	.55	.64	2.47 (687, 2748)	.000
	3	.74	.69	.79	3.87 (263, 1052)	.000

Appendix to results

Table S11.1. Model output from Experiment 3.

Predictors	β	*SE*	*t*	*p*
(Intercept)	6.334	.007	934.0	< .001***
Congruency (*incongruent)*	-.002	.001	-1.88	.061
Familiarity (*unfamiliar*)	-.001	.001	-.78	.445
Congruency* Familiarity	.002	.001	-2.00	.047*
Random effects	*Variance*	*SD*		
ID (intercept)	.020	.141		

Number of observations: 16949, ID: 444. Note that results are given on the log (not the response) scale. For clarity, 3 decimals are reported for the estimate, standard error, variance, and standard deviation.

Table S11.2. Exploratory analysis: Testing for effects of sex-combinations (dot-probe participant and photo participant), familiarity and congruency on reaction times in Experiment 3.

Predictors	χ^2	*df*	*p*
Sex combination (*M-M, M-F, F-M, F-F*)	1.46	3	.691
Congruency (*congruent, incongruent)*	1.46	1	.227
Familiarity (*familiar, unfamiliar*)	.61	1	.434
Sex combination*Congruency*Familiarity	1.44	3	.696
Random effects	*Variance*	*SD*	
ID (intercept)	.00	.07	
Residual	.02	.16	

Number of observations: 15326, ID: 402. Note that results are given on the log (not the response) scale, and that some samples are missing because we lost some data relating to sex and relationship. M = male, F = female.

Appendix B

Supplementary Materials for Chapter 4

Appendix to stimuli

Table S1. Definitions of emotion categories of bonobo and human stimuli.

Picture category	bonobo	human
Distress	Aggressive displays, such as long and short charges, mutual and direct displays; submissive behaviours such as grin faces, fleeing, and crouching	Fearful displays (wide-open eyes, raised eye brows, open mouth) which may include crying and embracing
Sex	Mating, genito-genital rubbing, masturbation, prominent full swelling, penile erection	Man and woman in underwear romantically embracing and/or kissing, no genitals or penetration visible
Playing	Together or alone, with a relaxed open mouth, without an object	See bonobo
Grooming	Two or more individuals grooming with close physical contact	Two or more individuals in close physical contact, hugging, smiling, or brushing hair
Yawning	Wide open mouth with or without canine visibility	Wide open mouth with or without teeth visible
Neutral	Walking, lying down, or sitting	Walking, lying down, sitting, running, cycling

Table S2. Overview of number of individuals, adults, juveniles, males and females per picture category for bonobo stimuli

Picture category	No. of individuals		No. of adults		No. of juveniles / infants		No. of females*		No. of males*	
	M	SD	M	SD	M	SD	M	SD	M	SD
Distress	1.22	0.44	0.67	0.71	0.56	0.53	0.78	0.44	0.44	0.53
Sex	1.80	1.23	1.50	0.97	0.30	0.67	1.20	1.03	0.60	0.52
Play	1.88	0.99	0.63	0.74	1.25	0.71	1.00	0.93	0.88	0.83
Groom	2.50	0.85	2.10	0.74	0.40	0.52	1.80	0.79	0.70	0.95
Yawn	1.00	0.00	0.91	0.30	0.09	0.30	0.18	0.40	0.82	0.40
Neutral	1.75	1.21	1.23	0.81	0.52	0.90	0.98	0.84	0.77	0.86

* Since stimuli were collected from the internet, it was not always possible to deduct whether an individual was male or female (e.g., when only part of the body was visible).

Table S3. Overview of number of individuals, adults, juveniles, males and females per picture category for human stimuli.

Picture category	No. of individuals		No. of adults		No. of juveniles / infants		No. of females		No. of males	
	M	SD	M	SD	M	SD	M	SD	M	SD
Distress	6.00	3.77	4.90	4.01	1.10	3.14	4.00	3.83	3.70	3.71
Sex	2.00	0.00	2.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00
Play	2.80	1.81	1.90	2.42	0.90	1.10	1.80	1.93	1.00	0.67
Groom	3.60	2.76	3.20	3.01	0.50	0.71	2.00	1.94	1.80	1.87
Yawn	1.50	1.27	0.90	1.52	0.60	0.52	0.90	0.99	0.60	0.70
Neutral	5.37	3.68	5.26	3.72	0.29	0.64	3.61	3.52	3.80	3.68

Appendix to calibration of bonobos

During data collection, we displayed a 9-point grid to the bonobos at the beginning of each session to visually inspect calibration accuracy through Tobii Live Viewer (Figure S1). Nevertheless, after data collection ended and checking the raw data, we noticed that for two bonobos (Zuani and Monyama), there were consistent shifts in the gaze data either to the left or right relative to the position of the stimuli on the screen. To make sure our measure of interest, *Total fixation duration*, was as accurate as possible, we decided to correct the specific cases in which we could see a shift. We therefore developed a python script to establish the gaze offsets per session for Zuani and Monyama. Per session, we used K-means clustering to calculate the two centroids (i.e., the mean position of all points within a 2-dimensional space) of the gaze data on the left and right stimulus, and compared the X and Y coordinates of these centroids to the true center points of the left and right stimuli on the screen. The average offset to the left or right on the X-axis relative to the true center points was then used to calculate the adjusted regions of interest for a specific session. In Figure S2 down below you can see an example of this. For the data analyses, we did not manipulate the raw gaze data, but rather adjusted the regions of interest in Tobii Studio to accommodate the offset (see Figure S3).

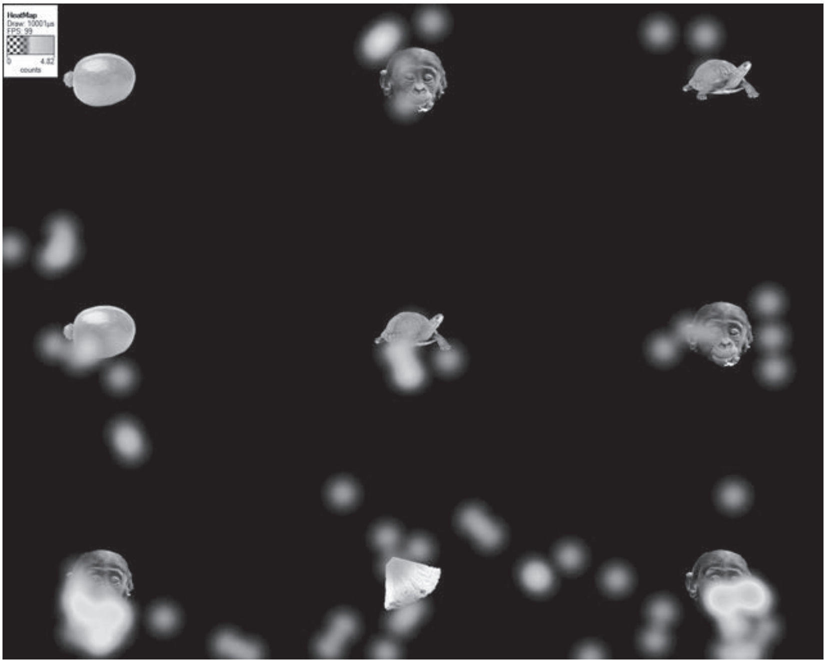

Figure S1. Example of the 9-point grid shown to the bonobos at the start of each session, here displayed with a heatmap (with green indicating lower, and red indicating higher fixation counts).

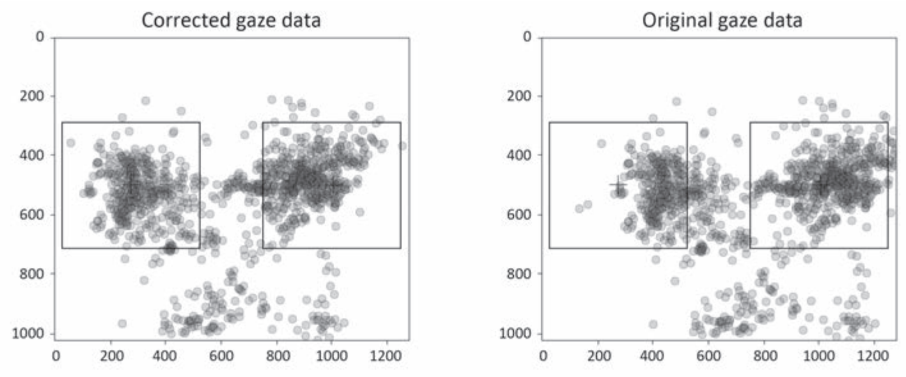

Figure S2. Example of a session in which gaze data was consistently shifted to the left relative to the positions of the stimuli (blue and orange squares) on the screen. On the right, the original gaze data of a specific session of one individual (Monyama) is plotted. For clarity, we also plotted what the corrected gaze data would look like applying K-means clustering.

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Figure S3. Example of what (corrected) region of interests (ROI) could look like. On the left, the normal ROIs are displayed. On the right, the corrected ROIs for the specific session displayed in S1 are displayed.

Appendix to results experiment 1

Table S4. Overview of results of the bonobos.

	Model 1	Model 2	Model 3
Predictor	β *(89% CI)*	β *(89% CI)*	β *(89% CI)*
Intercept	-0.01 [-0.15 – 0.13]	0.06 [-0.08 – 0.20]	0.18 [0.02 – 0.33]
Species (human)		-0.16 [-0.23 – -0.09]	-0.08 [-0.23 – 0.08]
Emotion category (groom)			-0.21 [-0.35 – -0.06]
Emotion category (play)			-0.20 [-0.35 – -0.05]
Emotion category (sex)			-0.04 [-0.17 – 0.11]
Emotion category (yawn)			-0.17 [-0.32 – -0.04]
Species (human) * Emotion category (groom)			0.05 [-0.17 – 0.26]
Species (human) * Emotion category (play)			0.11 [-0.10 – 0.32]
Species (human) * Emotion category (sex)			-0.49 [-0.70 - -0.28]
Species (human) * Emotion category (yawn)			-0.06 [-0.27 – 0.15]
Random effects			
σ^2	1	1	1
τ_{00}	0.03_{ID}	0.02_{ID}	0.02_{ID}
	$0.00_{ID:Session}$	$0.00_{ID:Session}$	$0.00_{ID:Session}$
N	$134_{Session}$	$134_{Session}$	$134_{Session}$
	4_{ID}	4_{ID}	4_{ID}
Observations	1420	1420	1420

Note: All values are reported on the log scale.

Appendix to results experiment 2

Table S5. Overview of results per model, per factor.

	Model 1	Model 2	Model 3
Predictor	β *(89% CI)*	β *(89% CI)*	β *(89% CI)*
Intercept	0.13 [0.10 – 0.16]	0.06 [0.02 – 0.10]	-0.08 [-0.15 – -0.01]
Species (human)		0.13 [0.09 – 0.18]	0.32 [0.22 – 0.41]
Emotion category (groom)			0.24 [0.15 – 0.34]
Emotion category (play)			0.22 [0.13 – 0.32]
Emotion category (sex)			0.12 [0.03 – 0.22]
Emotion category (yawn)			0.11 [0.02 – 0.20]
Species (human) * Emotion category (groom)			-0.26 [-0.39 – -0.13]
Species (human) * Emotion category (play)			-0.25 [-0.39 – -0.12]
Species (human) * Emotion category (sex)			-0.13 [-0.27 – 0.00]
Species (human) * Emotion category (yawn)			-0.30 [-0.43 – -0.17]
Random effects			
σ^2	1	1	1
τ_{00}	0.02_{ID}	0.02_{ID}	0.02_{ID}
N	94_{ID}	94_{ID}	94_{ID}
Observations	2780	2780	2780

Note: All values are reported on the log scale.

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Appendix C

Supplementary Materials for Chapter 5

Appendix to participants and data collection

Table S1. Additional information about the study subjects

Name	Sex	Birth year	Developmental stage	Minutes of observation	Relationship
Amos	Male	2000	Adult	1120	Father of Kawan and Baju
Baju	Male	2015	Juvenile	NA	Son of Amos and Wattana
Binti	Female	2000	Adult	1090	No kin in the group
Dayang	Female	2005	Adult	1120	Adopted by Sandy
Kawan	Male	2010	Adolescent (unflanged)	1090	Son of Wattana
Kevin	Male	1982	Adult	1110	Born in the wild, no kin in the group
Samboja	Female	2005	Adult	1080	Daughter of Sandy
Sandy	Female	1982	Adult	1110	Mother of Samboja
Silvia	Female	1965	Adult	1080	No kin in the group
Wattana	Female	1995	Adult	1110	Mother of Kawan and Baju

Table S2. Ethogram of the orangutans

	Behavior	Code	Description
Infant	Nursing	N	Infant suckling from nipple unaided (dur)
	Retrieve	R	Retrieve infant from another animal or physical structure (dur)
Socio-positive	Allogrooming	GR	One individual picking, stroking or parting of hair over any part of the body with mouth or hands of another individual (dur)
	Being groomed	BG	Focal animal is groomed by another animal (dur)
	Contact	C	Mouth-mouth contact, olfactory inspection, touch (dur)
	Contact sitting	CS	Sitting next to other individual (dur)
	Play	P	Mouth fighting or wrestling (dur)
Agonistic	Chase other	CH	Individual pursuing another using any form of locomotion (dur)
	Direct aggression	FI	Biting/hitting/grabbing (dur)
	Display	DI	Charge, shaking of climbing structure/rope (dur)
	Make way	MW	Move out of the way when another animal is approaching (pt)
Sexual	Genital contact	GC	One individual touching hand/mouth to another's genital area (dur)
	Mount	M	Mounting another animal in a copulatory position; genital-genital contact established (dur)
Food associated	Drinking	DR	Drink from drink-nipple (pt)
	Feeding	FE	Actively eating, reaching for food, processing or preparing food items (dur)
	Foraging	FO	Searching for food (dur)
	Give food	GF	Give food to another animal (pt)
	Take food	TF	Take food from another animal's mouth or hand (pt)
Locomotion	Brachiate/climbing	CL	Hand-over-hand locomotion (dur)
	Walk	W	Forward or backward locomotion either quadrupedally or bipedally (dur)
Facial expression	Funnel face	FF	Maximal pursing of the lips (pt)
	Grimace	GR	Teeth showing, mouth slightly open, corners pulled back (pt)
Vocalization	Grunt	G	Deep, belch-like vocalization (dur)
	Kiss squeak	KS	Vocalization made by the intake of air through extended lips (dur)
	Long call	LC	Deep, rumbling vocalization (dur)
	Auto-groom	AG	Picking, stroking or parting of own hair over any part of the body (dur)
	Auto-play	AP	Animal plays with food/items alone (dur)
	Caretaker	CA	Interacting/waiting for interactions with the caretaker (dur)
	Nest building	NB	Preparation of day/night nest (dur)
	Object manipulation	OM	Manipulating object with hand/mouth (dur)
Other	Out of sight	OS	Animal is out of sight (dur)
	Resting	R	Laying (in a nest), not sleeping (eyes opened) (dur)
	Self-scratching	SC	Auto-scratch (dur)
	Sleeping	SL	Resting without locomotion, eyes are closed (dur)
	Yawn	Y	Opening of mouth and lips with teeth bared or not visible (pt)

Dur = duration behavior, pt = point behavior

A

Appendix to results

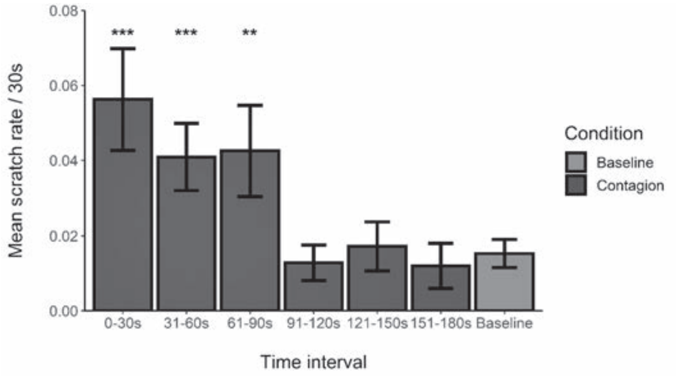

Figure S1. Mean self-scratch rates (± *SEM*) in the six 30 second intervals in the contagious condition compared to the baseline self-scratch rate. *** $p < 0.001$, ** $p < 0.01$.

Appendix D

Supplementary Materials for Chapter 6

Appendix to participants and procedure

Table S1. Overview of test subjects, their sex, age, and relationship.

Name	Sex	Birth year	Developmental stage	Relationship
Amos	Male	2000	Adult	Father of Kawan, Baju, and Indah
Baju	Male	2015	Juvenile	Son of Amos and Wattana
Indah	Female	2017	Infant	Daughter of Amos and Samboja, granddaughter of Sandy
Kawan	Male	2010	Adolescent (unflanged)	Son of Amos and Wattana
Kevin	Male	1982	Adult	Born in the wild, no kin in group
Sandy	Female	1982	Adult	Mother of Samboja, grandmother of Indah
Samboja	Female	2005	Adult	Daughter of Sandy, mother of Indah
Wattana	Female	1995	Adult	Mother of Kawan and Baju

Note: Two adult females (Wattana and Samboja) were always housed with their offspring and sometimes with one adult male.

Test sessions were carried out in mornings and afternoons (between 10:00-15:30) in the inside enclosures (Figure 1 in Chapter 6). During testing, two observers and occasionally a zookeeper were presen. Sometimes, volunteer guides belonging to the park visited the orangutans during testing. Furthermore, nearing the end of the testing period one of the individuals had fallen ill and therefore two caretakers were present during testing almost daily. At the beginning of every session, the screen was placed in front of one of the enclosures. An enclosure usually housed one to four individuals (often mother-offspring and one adult male), and testing only started when the focal individual was in a position that allowed it to see the screen. Furthermore, if a focal individual did not see at least one full clip (yawn or control), another attempt was made by moving the screen or waiting until the focal was in a suitable position. All individuals in the enclosure were filmed with two cameras. If the focal individual moved, the observers adjusted the position of the screen as well.

Yawns that occurred during the primer or while it was clear that the subject had no direct line of sight towards the screen when the stimuli were presented, were recorded as spontaneous yawns and not taken into account in subsequent analyses. Note however, that the number of spontaneous yawns was almost exactly equal between the two conditions (18 and 17 in the yawn and control condition, respectively).

Appendix to results

Table S2.1. Overview of yawning *occurrences* per individual in yawn and control conditions and across triggers.

Trigger	Familiar		Unfamiliar		Avatar		
Individual	Yawns in Control	Yawns in Yawn	Yawns in Control	Yawns in Yawn	Yawns in Control	Yawns in Yawn	Total
Amos	2	6	0	1	2	1	12
Baju	1	2	0	0	1	2	6
Indah	0	0	0	1	0	0	1
Kawan	2	2	6	6	1	1	18
Kevin	0	2	0	1	0	0	3
Samboja	0	0	0	0	0	0	0
Sandy	0	1	0	1	0	0	2
Wattana	0	1	0	1	0	1	3
Total	5	14	6	11	4	5	45

Table S2.2. Overview of yawning *rates* per individual in yawn and control conditions and across triggers.

Trigger	Familiar		Unfamiliar		Avatar		
Individual	Yawns in Control	Yawns in Yawn	Yawns in Control	Yawns in Yawn	Yawns in Control	Yawns in Yawn	Total
Amos	2	8	0	1	2	1	14
Baju	3	8	0	0	2	4	17
Indah	0	0	0	1	0	0	1
Kawan	2	4	9	21	1	1	38
Kevin	0	2	0	3	0	0	5
Samboja	0	0	0	0	0	0	0
Sandy	0	4	0	1	0	0	5
Wattana	0	1	0	1	0	1	3
Total	7	27	9	28	5	7	83

Table S2.3. Overview of overall yawning *occurrences* and *rates* in the yawn and control condition per replication cycle

	Replication	Control	Yawn	Total
Yawn occurrences	1	7	8	15
	2	1	7	8
	3	2	6	8
	4	5	9	14
	Total	15	30	45
Yawn rates	1	7	16	23
	2	1	11	12
	3	3	17	20
	4	10	18	28
	Total	21	62	83

Table S3. Overview of number of trials per individual, per trigger and per condition.

Trigger	Familiar		Unfamiliar		Avatar		
Individual	Control	Yawn	Control	Yawn	Control	Yawn	Total
Amos	17	14	13	11	13	15	83
*Baju	9	6	9	6	4	10	44
*Indah	14	14	13	16	11	11	79
*Kawan	19	18	21	19	18	18	113
Kevin	17	14	17	15	15	16	94
Samboja	14	16	14	15	17	15	91
Sandy	15	19	16	18	14	13	95
Wattana	18	12	19	18	16	18	101
Total	123	113	122	118	108	116	700

* Baju and Kawan are the offspring of Wattana. Indah is the offspring of Samboja. Note: The numbers are not equally divided across individuals, as bystanders were present in the same enclosure as the focal were also exposed to the videos (for instance in the case of mother-offspring pairs). Furthermore, within individuals, numbers are not equal between conditions because in some cases the focal individual paid no attention to the screen, leading to no data for these particular trials. Finally, one video was accidentally presented an extra time, which means that after data collection we had 289 rather than the planned 288 sessions.

Testing the link between yawn occurrence, condition, and familiar and unfamiliar trigger (excluding avatar)

As CY seemed to be present only in response to a familiar or unfamiliar trigger, but not significantly so with the avatar trigger, we performed an extra exploratory analysis without the avatar trigger. Specifically, we first tested whether yawn occurrence is moderated by *condition* (yawn vs. control), *trigger* (familiar vs. unfamiliar), and their interaction using a binomial GLMM with *subject* nested in *trial*. Next, in those cases that at least one yawn occurred, we tested whether yawning rate is moderated by *condition, trigger,* and their interaction using a negative binomial GLMM with *subject* nested in *trial*.

In the first analysis looking at the likelihood of yawning, we re-confirmed the presence of CY in the reduced dataset: we found a main effect of *condition* ($\beta = 6.74$, $SE = 1.65$, $Z = 4.082$, $p < .001$) in which individuals were more likely to yawn in the yawn vs. control condition. We did not find evidence for an interaction between *condition*trigger* ($\beta = -3.24$, $SE = 2.05$, $Z = 1.57$, $p = .115$). Despite our reduced dataset, we still confirm the presence of CY in orangutans, but find no evidence for a familiarity effect using 'real' orangutan stimuli only.

In the second analysis in which we looked at yawning rates, we found no significant main effect of *condition* ($\beta = .37$, $SE = .46$, $Z = .81$, $p = .420$), nor an interaction effect between *condition*trigger* ($\beta = .32$, $SE = .61$, $Z = .52$, $p = .603$). Similar to the original analysis including the avatar trigger, we find no differences in strength between conditions and triggers. The model including the interaction between *condition* and *trigger* did not significantly improve the null model ($\chi^2(3) = 3.50$, $p = .321$).

Testing the link between contagious yawning, condition and familiarity using self-scratching as covariate

To control for self-scratching in our models that investigate the presence and strength of contagious yawning, we perform two Hurdle models, each containing two analyses. First, using a binomial GLMM with Subject nested in Trial as random factors and condition and self-scratch occurrence as fixed factors, we find a main effect of condition on the likelihood of yawning ($b = 3.52$, $SE = 1.05$, $Z = 3.35$, $p = .0008$), but no effect of self-scratch occurrence ($b = 1.33$, $SE = .96$, $Z = 1.39$, $p = .163$). In those cases that at least one yawn occurred, is the yawn response larger in the yawn condition versus the control condition? To answer this question, we perform a negative binomial GLMM with Subject nested in Trial as random factors and condition and self-scratch rate as fixed factors and compare this model to the null model (without fixed factors). The result shows that the alternative model cannot explain the data better than the null model: $\chi^2 2(2) = 3.32$, $p = .191$; there is no main effect of condition ($b = .47$, $SE = .26$, $Z = 1.80$, $p = .071$), nor a main effect of self-scratch rate ($b = .03$, $SE = .06$, $Z = .48$, $p = .634$) on yawn rate.

In the second hurdle model, we look at effects of familiarity on the occurrence and strength of contagious yawning. First, using a binomial GLMM with Subject nested in Trial as random factors and condition, trigger, condition*trigger, and self-scratch occurrence as fixed factors, we find a main effect of condition and condition*trigger on the likelihood of yawning, but no effect of self-scratch occurrence ($b = 1.33$, $SE = .96$, $Z = 1.39$, $p = .163$). Specifically, yawning is more likely to occur in the yawn versus control condition in case of a familiar trigger ($b = -6.50$, $SE = 1.64$, $Z = -3.97$, $p = .0001$) and an unfamiliar trigger ($b = -3.93$, $SE = 1.57$, $Z = -2.50$, $p = .012$). Next, in those cases that at least one yawn occurred, is the yawn response larger in the yawn condition versus the control condition and does familiarity affect this result? To answer these questions, we perform a negative binomial GLMM with Subject nested in Trial as random factors and condition, trigger, condition*trigger, and self-scratch rate as fixed factors and compare this model to its respective null model. The result shows that the alternative model cannot explain the data better than the null model: $\chi^2 2\ (6) = 5.30$, $p = .505$; there is no main effect of condition ($b = .18$, $SE = .62$, $Z = .28$, $p = .776$), nor a main effect of self-scratch rate ($b = .04$, $SE = .07$, $Z = .58$, $p = .560$), nor an interaction between condition*trigger ($b = .19$, $SE = .76$, $Z = .26$, $p = .798$) on yawn rate.

As such, we confirm that orangutans yawn contagiously in response to “real” orangutan stimuli, regardless of whether they are familiar or not. Furthermore, we cannot draw any conclusions on the rate of yawning. Importantly, self-scratching does not have a significant impact on the occurrence of the aforementioned results.

Appendix E

Supplementary Materials for Chapter 7

Experiment 1: PIAT in the zoo

Appendix to stimuli and procedure

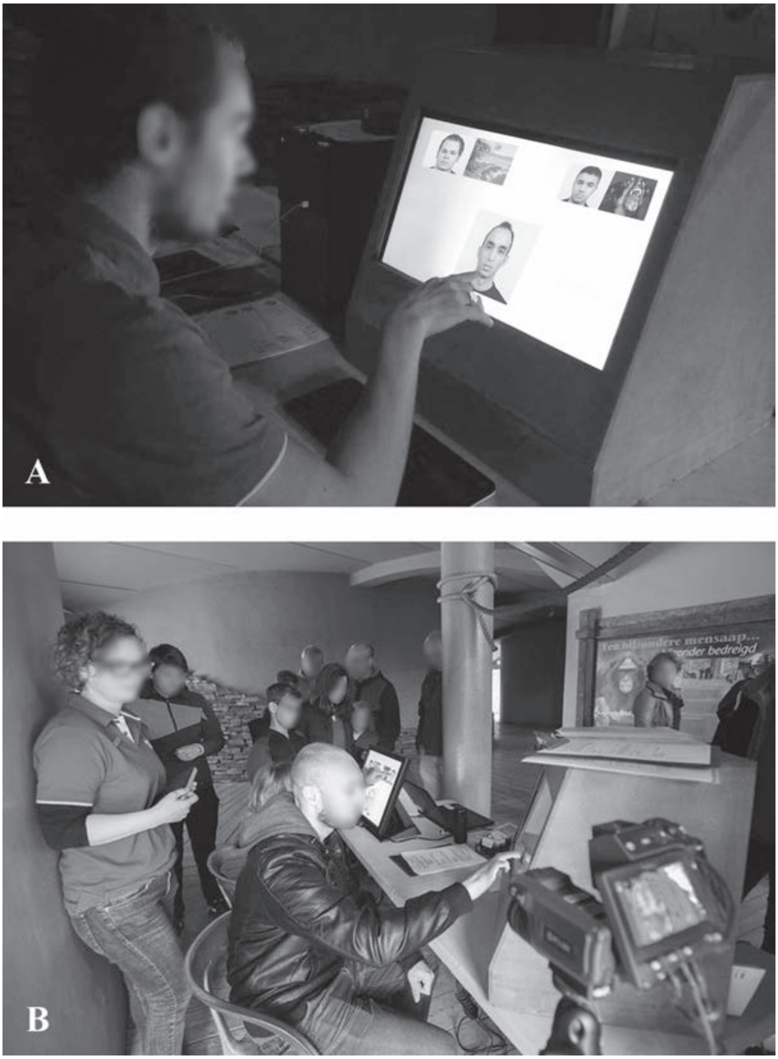

Figure S1. (A) Close-up of test setup used by the adults. (B) Photo of test environment (taken during a practice round). Photos were taken with permission.

Table S1.1. Overview of concept stimuli used in the adult and child P-IAT. The stimuli form a subset of the Radboud Faces Database (RaFD; Langer et al., 2010).

RaFD Image Name	Agreement between subjects	Intensity	Clarity	Genuineness	Valence
Rafd090_09_Dutch_male_ neutral_frontal*	87	3.30	3.74	3.65	2.87
Rafd090_10_Dutch_male_ neutral_frontal	86	3.55	3.86	3.82	2.95
Rafd090_20_Dutch_male_ neutral_frontal	68	2.82	3.32	3.55	2.68
Rafd090_24_Dutch_male_ neutral_frontal	96	3.84	4.16	4.24	3.24
Rafd090_28_Dutch_male_ neutral_frontal	88	3.36	3.76	3.92	2.88
Rafd090_36_Dutch_male_ neutral_frontal	100	3.92	3.92	4.04	3.24
Rafd090_35_Moroccan_male_ neutral_frontal	100	3.95	4.45	3.90	2.95
Rafd090_45_Moroccan_male_ neutral_frontal*	75	3.30	3.75	3.90	2.75
Rafd090_51_Moroccan_male_ neutral_frontal	89	3.68	4.11	4.05	3.05
Rafd090_52_Moroccan_male_ neutral_frontal	100	3.35	3.90	4.25	3.30
Rafd090_55_Moroccan_male_ neutral_frontal	95	3.55	3.85	4.05	2.85
Rafd090_59_Moroccan_male_ neutral_frontal	100	3.70	4.00	4.30	3.10

* These concepts are used as exemplars to indicate the "Dutch" and "Moroccan" categories.

Table S1.2. Overview of attribute stimuli used in the adult version of the P-IAT. Images form a subset of the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert (2008).

Negative/Positive Attribute	Image Description	IAPS code	Valence (*SD*)	Arousal (*SD*)
neg1	Explosion*	9940	1.62(1.20)	7.15(2.24)
neg2	Injecting	9590	3.08(1.63)	5.41(2.23)
neg3	Snake	1120	3.79(1.93)	6.93(1.68)
neg4	Spider	1200	3.95(2.22)	6.03(2.38)
neg5	Attackdog*	1304	3.37(1.58)	6.37(1.93)
neg6	Fire*	8485	2.73(1.62)	6.46(2.10)
pos1	Seal*	1440	8.19(1.53)	6.05(2.38)
pos2	Polarbears	1441	7.97(1.28)	3.94(2.38)
pos3	Rabbit	1610	7.82(1.34)	3.08(2.19)
pos4	Sunset	5830	8.00(1.48)	4.92(2.65)
pos5	Nature*	5760	8.05(1.23)	3.22(2.39)
pos6	Icecream*	7330	7.69(1.84)	5.14(2.58)

* These attribute-images are used as exemplars to indicate the positive and negative categories.
Note. Descriptions and valence and arousal ratings are taken from Lang, Bradley, & Cuthbert (2008).

Table S1.3. Overview of valence and arousal ratings for the attribute images used in the child P-IAT.

Positive/Negative	Image Description	Valence (SD)	Arousal (SD)
Negative 1	Teenage Mutant Ninja Turtles villain	3.80 (1.92)	3.80 (2.39)
Negative 2	Spongebob villain	3.75 (2.22)	2.00 (0.82)
Negative 3	Pokémon villain	4.50 (1.91)	4.75 (1.71)
Negative 4	Avatar villain	4.20 (2.39)	4.80 (1.79)
Negative 5	Fairly Odd Parents villain	2.00 (2.45)	4.00 (2.76)
Negative 6	Totally Spies villain	2.80 (2.17)	3.40 (1.94)
Positive 1	Teenage Mutant Ninja Turtles villain	4.50 (2.50)	4.50 (2.50)
Positive 2	Spongebob hero	5.83 (0.98)	4.33 (1.75)
Positive 3	Pokémon heroes	6.00 (1.41)	5.40 (1.81)
Positive 4	Avatar heroes	7.00 (.00)	6.83 (.43)
Positive 5	Fairly Odd Parents heroes	5.83 (.75)	4.33(1.75)
Positive 6	Totally Spies heroes	4.00 (1.58)	3.00 (2.35)

Table S2. Overview of different versions of the PIAT. Attribute stimuli differ between the child and adult version, but have the same name in the table.

Stim. Set	Task	Attribute		Critical Block 3			Critical Block 5		
		Left	Right	Congruency	Left	Right	Congruency	Left	Right
1	1	neg1	pos1	congruent	MLNL	DRPR	incongruent	DLNL	MRPR
1	2	neg1	pos1	incongruent	DLNL	MRPR	congruent	MLNL	DRPR
1	3	pos1	neg1	incongruent	MLPL	DRNR	congruent	DLPL	MRNR
1	4	pos1	neg1	congruent	DLPL	MRNR	incongruent	MLPL	DRNR
2	1	neg2	pos2	congruent	MLNL2	DRPR2	incongruent	DLNL2	MRPR2
2	2	neg2	pos2	incongruent	DLNL	MRPR	congruent	MLNL2	DRPR2
2	3	pos2	neg2	incongruent	MLPL2	DRNR2	congruent	DLPL2	MRNR2
2	4	pos2	neg2	congruent	DLPL2	MRNR2	incongruent	MLPL2	DRNR2
3	1	neg3	pos3	congruent	MLNL3	DRPR3	incongruent	DLNL3	MRPR3
3	2	neg3	pos3	incongruent	DLNL3	MRPR3	congruent	MLNL3	DRPR3
3	3	pos3	neg3	incongruent	MLPL3	DRNR3	congruent	DLPL3	MRNR3
3	4	pos3	neg3	congruent	DLPL3	MRNR3	incongruent	MLPL3	DRNR3

Abbreviations under columns Left and Right represent the valence and position of the image on the screen, i.e.: MLNL = Moroccan Left, Negative Left; DLNL = Dutch Left, Negative Left; MLPL = Moroccan Left, Positive Left; DLPL = Dutch Left, Positive Left. DRPR = Dutch Right, Positive Right; MRPR = Moroccan Right, Positive Right; DRNR = Dutch Right, Negative Right; MRNR = Moroccan Right, Negative Right

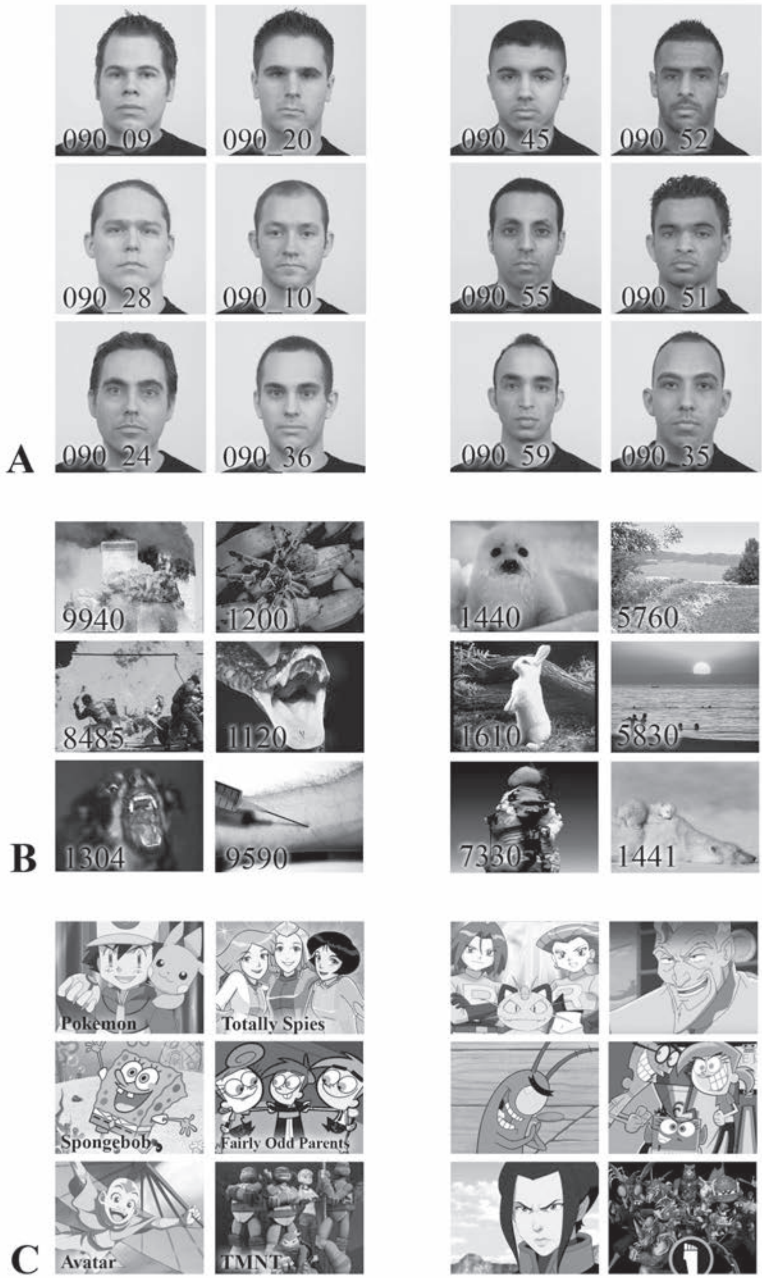

Figure S2. (A) The subset of Dutch and Moroccan faces selected from the Radboud Faces Database (Langer et al., 2010). (B) The subset of positive and negative image attributes selected from the International Affective Picture System (Lang, Bradley, & Cuthbert (2008), and used in the adult P-IAT. (C) The subset of positive and negative image attributes used in the child P-IAT. Images on the right represent the villains of the cartoons depicted on the left.

Figure S3. Overview of concept-attribute combinations for the adult (A) and child (B) P-IAT. In total, each version contains 24 unique combinations of concepts and attributes. Here we show only 12, but Dutch and Moroccan faces appeared either on the left or the right of a positive or negative attribute.

Appendix to results

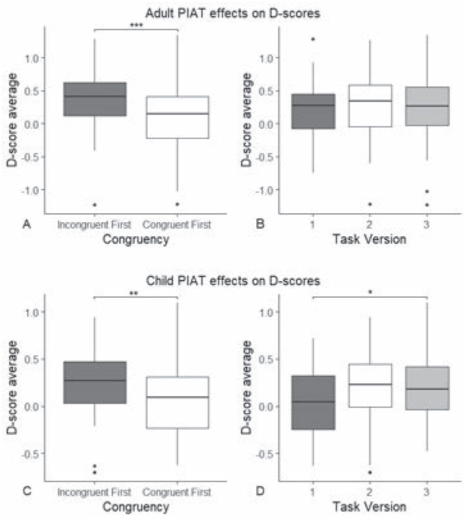

Figure S4. Box plots of effects of Congruency (A, C) and Task Version (B, D) on the Adult PIAT (A-B) and Child PIAT (C-D) D-score averages. *Task Version* represents the three different stimulus sets used in this study. D-scores are significantly higher for participants who receive incongruent trials first (A, C). Furthermore, task version 1 in the child PIAT shows a lower D-score average than version 2 and 3 (D). Outliers are visualized with a circle. * $p \leq .05$, ** $p < .01$. *** $p < .001$

Experiment 2: Online PIAT and WIAT

Appendix to procedure and results

Table S3. The randomization of starting positions for each block of the two IATs.

Block	Type	Trials	Tested	Version 1	Version 2	Version 3	Version 4
1	Training	20	Concepts only	M - D	M - D	D - M	D - M
2	Training	20	Attributes only	N - P	P - N	P - N	N – P
3	Experimental	20	Combined	MN - PD	MP - ND	DP - NM	DN - PM
4	Experimental	20	Combined	NM - DP	PM - DN	PD - MN	ND - MP
5	Training	20	Attributes only	P - N	N - P	N - P	P - N
6	Experimental	20	Combined	MP - ND	MN - PD	DN - PM	DP - NM
7	Experimental	20	Combined	PM - DN	NM - DP	ND - MP	PD - MN

Each participant only completed one randomly assigned version for each IAT. M = Moroccan ethnicity concept, C = Dutch ethnicity concept, P = positive attribute and N = negative attribute.

A

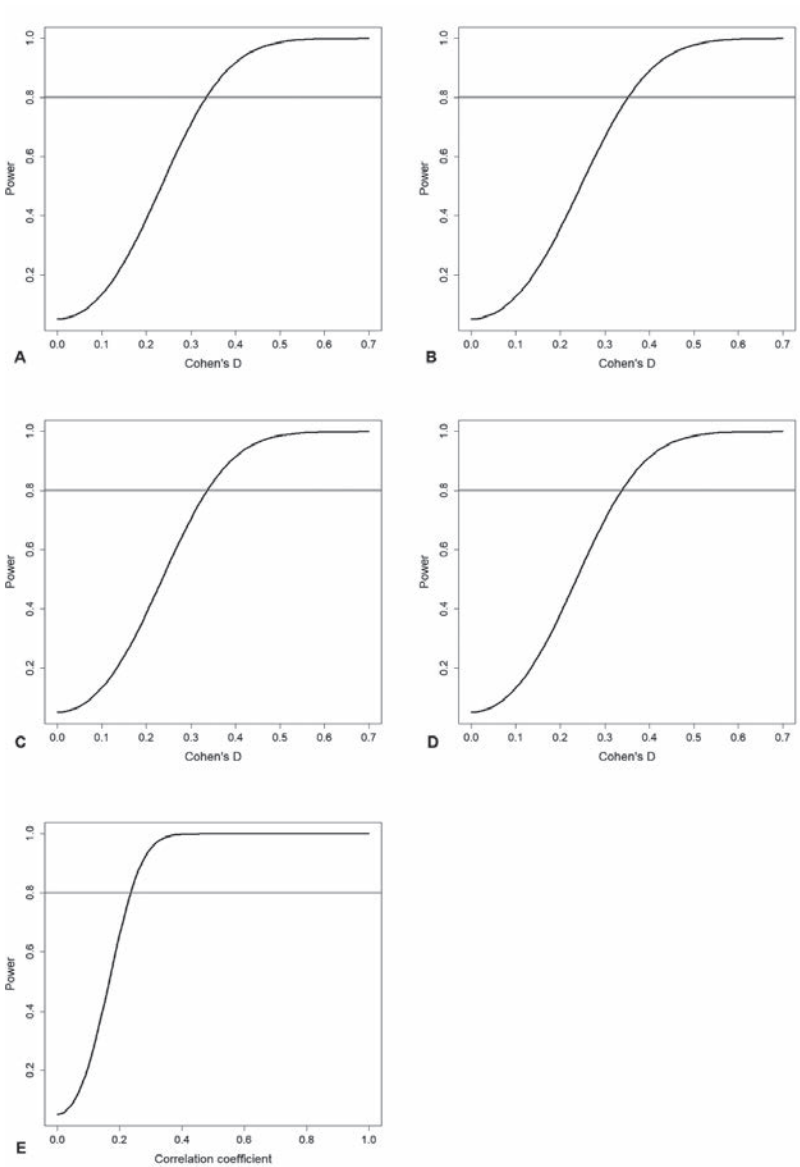

Figure S5. Curve results of the sensitivity power analyses (alpha = .05) for Experiment 1: A) Child PIAT, sample size = 142, B) Adult PIAT, sample size = 128, and Experiment 2: C) online PIAT, sample size = 140, D) online WIAT, sample size = 139, and E) correlation between the online PIAT and WIAT, sample size = 139. Given these sample sizes, we were able to detect true population effect sizes of (A): .34 (B): .35 (C): .34 (D): .34, and (E): .25 with ≥ 80% power (depicted with the horizontal red line).

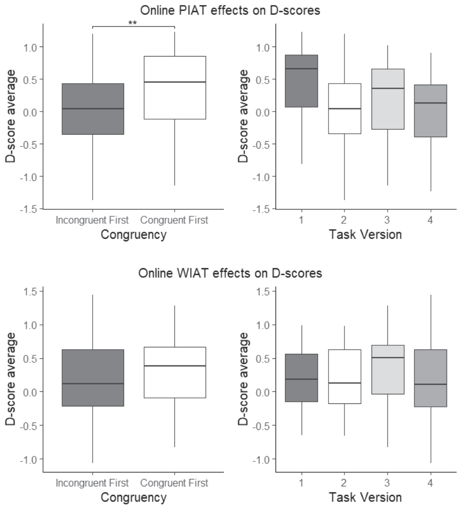

Figure S6. Box plots of the effects of Congruency and Task Version on D-scores in the online PIAT (top) and online WIAT (bottom). There was a significant effect of Congruency on D-score averages in the PIAT, with individuals receiving congruent trials first having higher D-scores averages. Task Version did not have a significant effect on scores in either the PIAT or WIAT. Finally, there was no Congruency effect in the WIAT.

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