Got a friend in me? Mapping the neural mechanisms underlying social motivations of adolescents and adults

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Supplementary materials

CHAPTER 2

FMRI Task

Participants played a heads-or-tails gambling game in which they could win or lose coins (Figure S1; also see Braams, Güroğlu, et al., 2014; Braams, Peters, et al., 2014; Braams et al., 2015). Participants started the game with 10 coins. On each trial, participants made a guess for heads or tails by pressing a button with their right index or middle finger. They won if the computer matched their response and lost if the computer did not match their response. Chances of winning on each trial were thus 50%. The first trial screen (4000 ms) showed how many coins they could win or lose. To keep the participants engaged in the task, three different types of distributions of coins were included: trials on which participants could win 3 or lose 3 coins, win 5 or lose 3 coins, and win 2 or lose 5 coins. A fixation screen followed the trial screen (1000 ms), and a feedback screen (1500 ms) followed the fixation screen and showed the outcome of the gambling decision. Trials ended with a jittered fixation screen (1000 – 13200 ms). Participants were instructed that the coins won in this task would translate to actual money, which would be paid out at the end of the experiment. In reality, all participants were randomly paid 4, 5, or 6 euros at T1 and T2, and they were paid 3 euros at T3. At T1 and T2 participants played 30 trials for themselves, 30 trials for their best friends, and 30 trials for another person. At T3, participants played 23 trials for themselves and 22 trials for their best friend. The aim of the current study was to investigate nucleus accumbens activation during rewards for the self; therefore only trials when participants played for themselves are included in the current analyses. It should be noted that there were fewer trials at T3 which was not accounted for in the analyses. We included all available data for the self condition (i.e., when participants played for themselves) from each time point.

Table S1. Number of scans obtained at T1, T2, and T3

Time point	Total	valid scans for analyses	scans excluded due to excessive motion (> 3mm)	scans excluded for other reasons[1]
T1	299	248	36	15
T2	255	226	10	19
T3	243	219	4	20

[1] *Other reasons to exclude scans than excessive motion were technical problems or artifacts, not finishing the task, reporting of a neurological or psychiatric disorder.*

Table S2. . Significance levels model comparisons testing the relation with age

Model Dependent variable	1 vs. 0	2 vs. 1	3 vs. 2	4 vs. Best model	5 vs. 4
Left NAcc Win > Lose	0.07	0.001	0.70	0.07	0.82
Right NAcc Win > Lose	0.03	< 0.001	0.97	0.58	0.83
Pleasure from Winning vs. osing	< 0.001	0.14	0.93	< 0.001	0.50
BAS Drive	0.02	0.58	0.03	0.57	0.02
BAS Fun Seeking	0.83	0.54	< 0.01	0.70	0.28
BAS Reward Responsiveness	0.36	0.65	0.01	0.01	0.39

[1]*Note. O = Null model, 1 = Linear model 2 = Quadratic model, 3 = Cubic model, 4 = Best model + Main effect Sex, 5 = 4 + Sex x Age interaction.*

[2]*Note. Preferred models are in* bold.

Table S3. Significance levels model comparisons testing the relation with NAcc activation

Predictor	Left NAcc Win > Lose: Model 1 vs. 0	Left NAcc Win > Lose: Model 2 vs. 1	Left NAcc Win > Lose: 3 vs. Best model	Left NAcc Win > Lose: Model 4 vs. 3	Right NAcc Win > Lose: Model 1 vs. 0	Right NAcc Win > Lose: Model 2 vs. 1	Right NAcc Win > Lose: 3 vs. Best model	Right NAcc Win > Lose: Model 4 vs. 3
Early to Mid adolescents								
Pleasure from Winning vs. Losing	0.16	0.58	-	-	0.10	0.48	-	-
BAS Drive	**0.03**	0.55	0.16	0.09	**0.02**	0.73	0.84	0.41
BAS Fun Seeking	0.07	0.42	-	-	0.39	0.63	-	-
BAS Reward Responsiveness	0.37	0.45	-	-	0.38	0.62	-	-
Mid-Adolescents to Young Adults								
Pleasure from Winning vs. Losing	< 0.01	**< 0.001**	0.60	0.46	< 0.001	**< 0.001**	0.60	0.99
BAS Drive	0.96	**< 0.001**	0.19	0.88	0.96	**< 0.001**	0.28	0.85
BAS Fun Seeking	0.73	**< 0.001**	0.17	0.70	0.68	**< 0.001**	0.24	0.73
BAS Reward Responsiveness	0.50	**< 0.001**	0.13	0.70	0.35	**< 0.001**	0.17	0.68

[1] *Note. 0 = Null model, 1 = model with Predictor, 2 = model with Predictor + Age, 3 = Best model + main effect Sex, 4 = 3 + Sex x Predictor interaction.*

[2] *Note. Preferred models are in* ***bold****.*

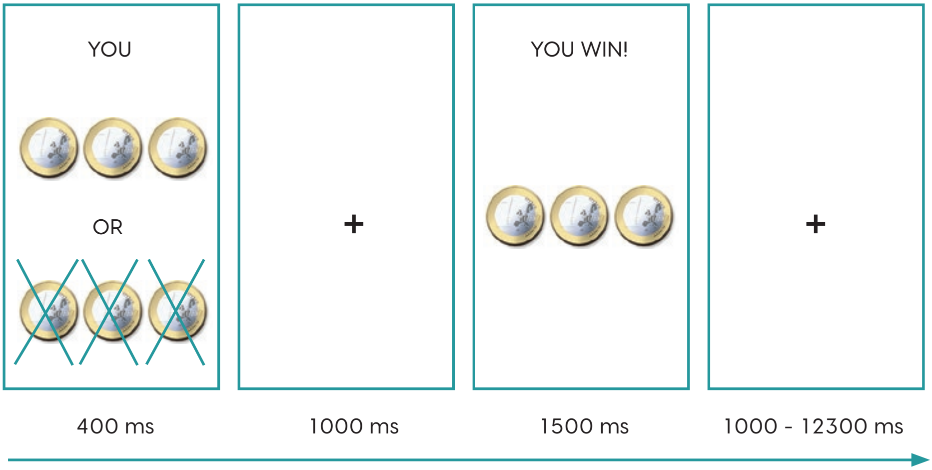


Figure S1. Example of one trial of the fMRI task.

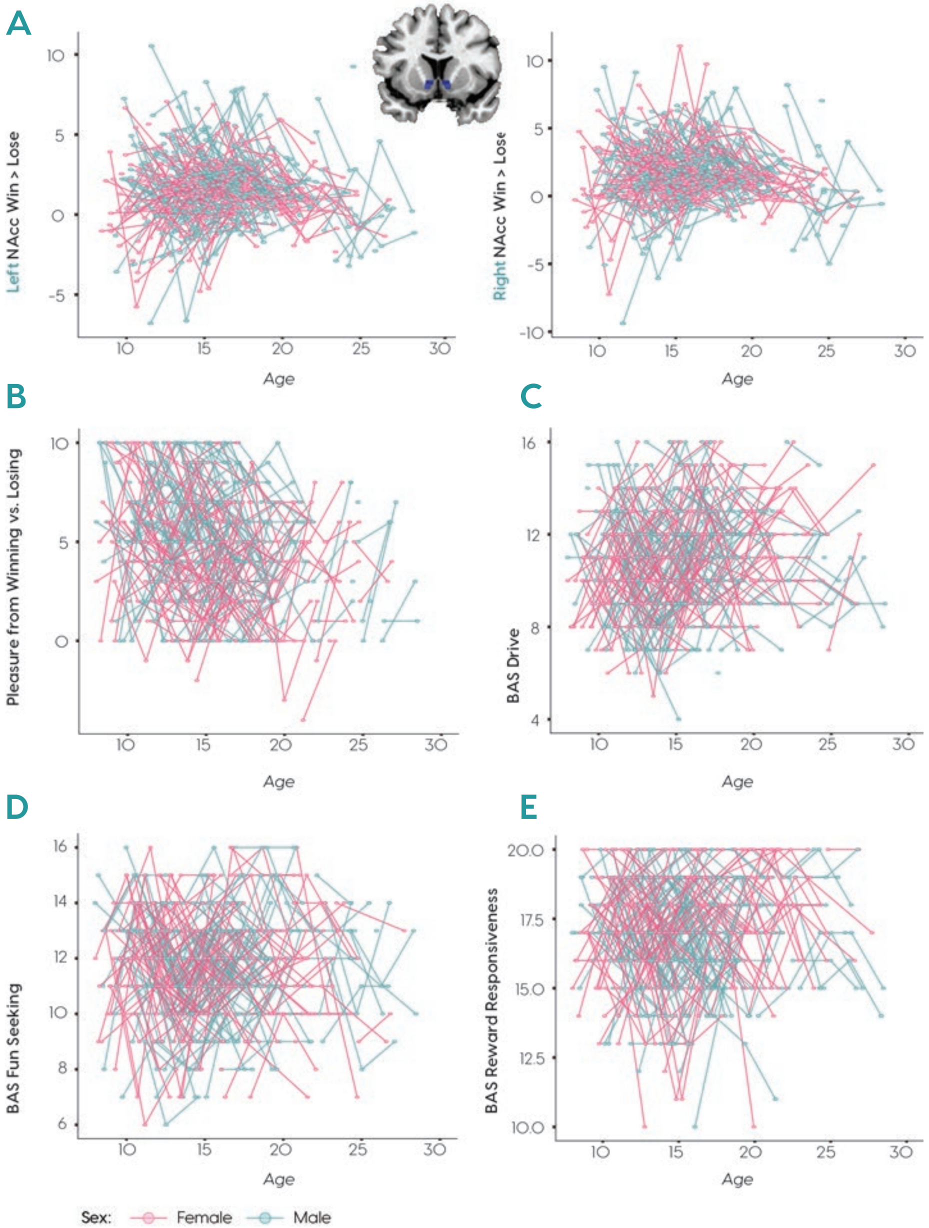


Figure S2. Raw data of (A) left and right NAcc activation during winning vs. losing, (B) self-reported pleasure from winning versus losing, (C) BAS drive, (D) BAS fun seeking, and (E) BAS reward responsiveness across development. *The connected points represent the participants, red for females and blue for males.*

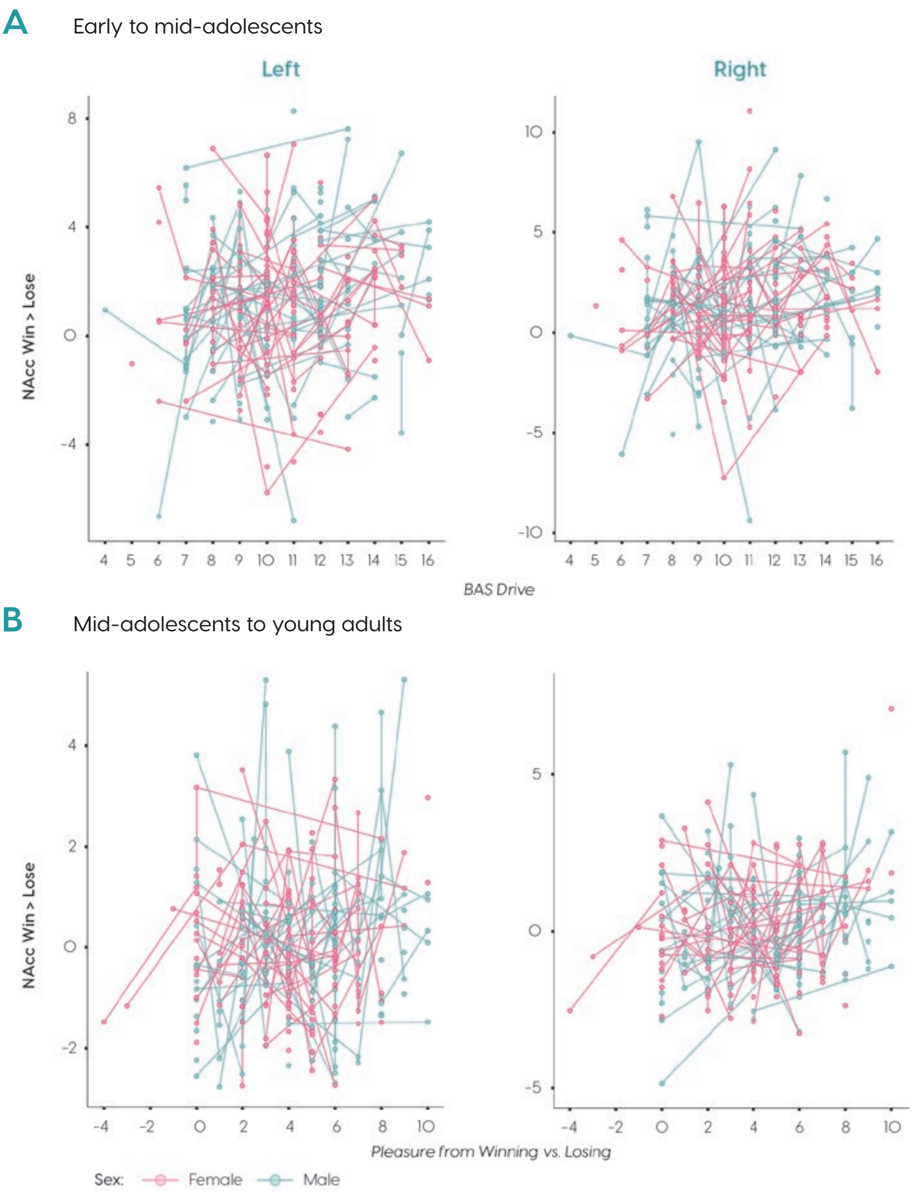


Figure S3. Raw data of the relation between left and right NAcc activation during winning versus losing and (A) BAS drive scores from early to mid-adolescent males and females, and (B) pleasure from winning vs. losing corrected for the main effect of age from mid- to late adolescents and young adult males and females. *The connected points represent the participants, red for females and blue for males.*

CHAPTER 3

Whole Brain Analysis:
Winning versus Losing for Best Friend

We examined which brain regions showed significantly increased activation during winning > losing for a best friend with a whole brain analysis of variance (ANOVA) with three factors: type of friendship (2 levels: stable and unstable), feedback (2 levels: winning or losing for friend), and time point (3 levels: T1, T2, and T3). We examined main effects of and interactions with feedback and friendship type. As expected, there was a main effect of feedback in the ventral striatum showing higher activity during winning than losing for the friend (Figure S1; Table S1). There were no effects of friendship type, and no interactions.

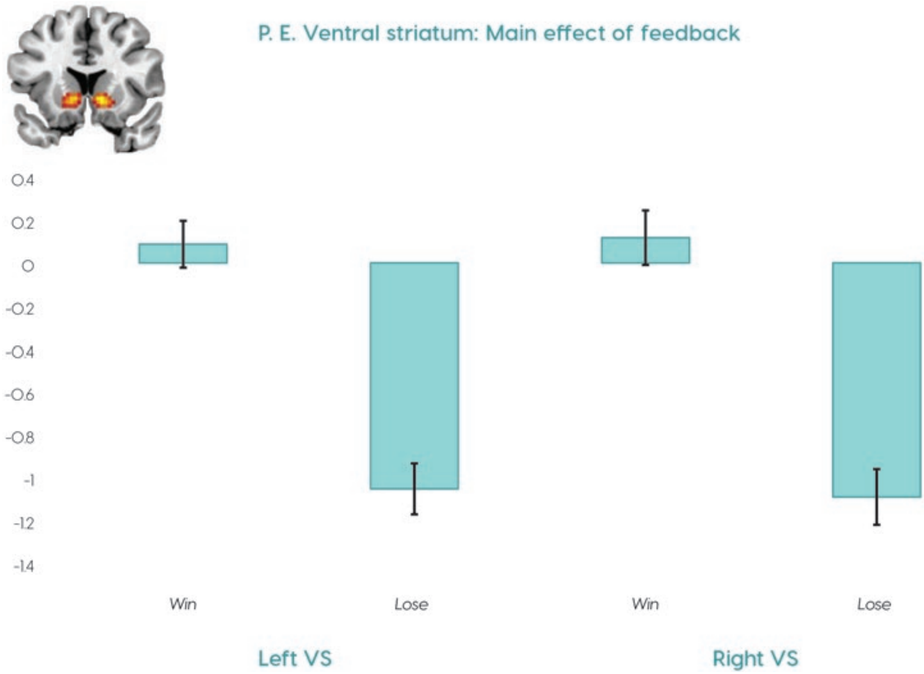


Figure S1. Main effect of feedback when playing for friends within a 2 [win or lose] x 2 [stable or unstable best friendship] x 3 [T1, T2, or T3] whole brain ANOVA. *P.E. = Parameter estimates, VS = Ventral striatum.*

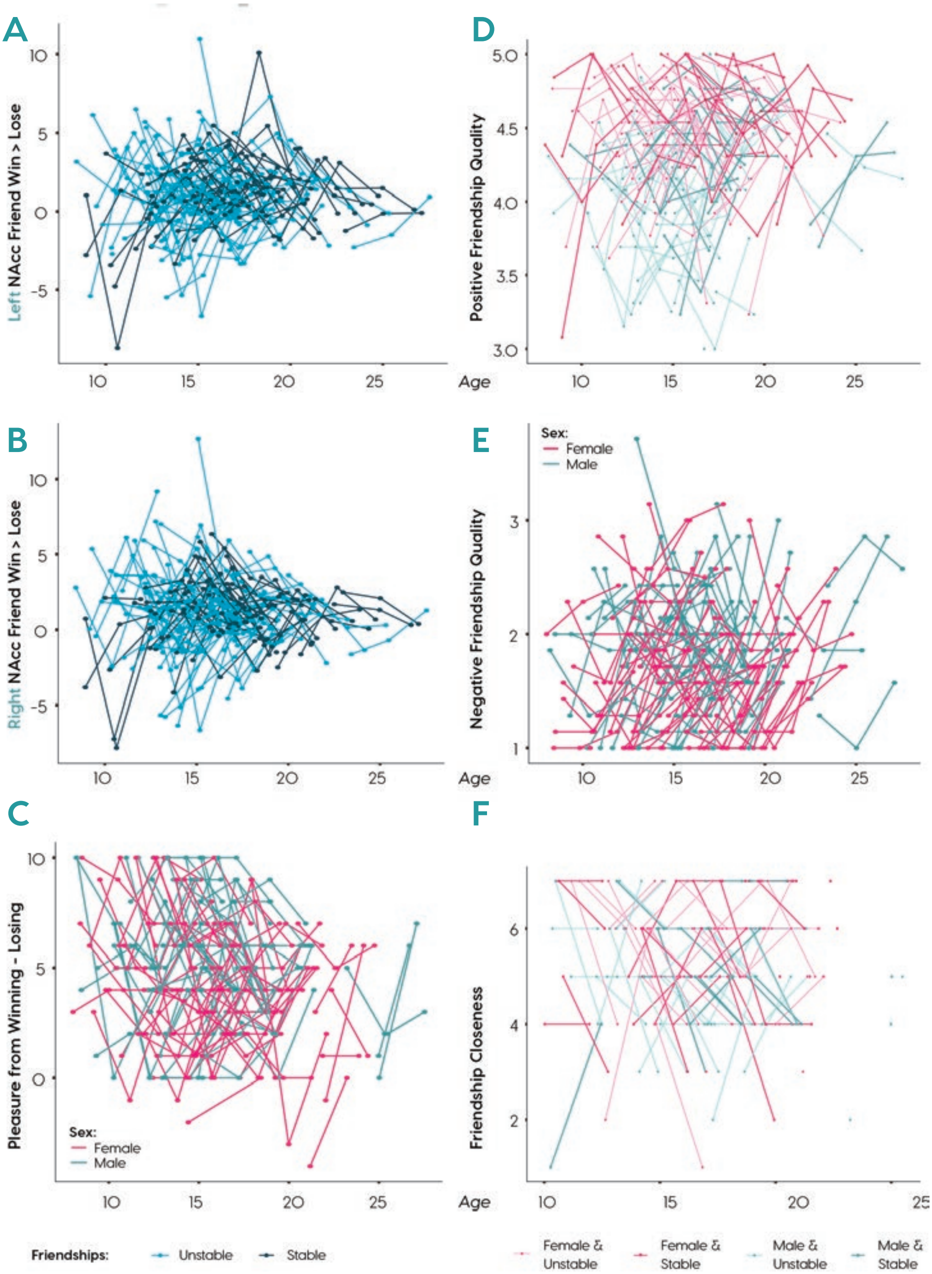


Figure S2. Raw data of the age-related patterns and effects of sex and friendship. *A) left NAcc activity, B) right NAcc activity, and C) pleasure from winning, D) positive friendship quality, E) negative friendship quality, and F) friendship closeness.*

Correlations between Pleasure from Winning, Friendship Quality, and Closeness

Partial correlation analyses were conducted to examine relations between positive and negative friendship quality, friendship closeness, and pleasure from winning within time points corrected for age (Table S2). At T1 positive and negative friendship quality correlated negatively ($p < .001$). There were no significant correlations at T1 for pleasure from winning and friendship quality (*ps* > .23). At T2, positive friendship quality correlated negatively with negative friendship quality ($p < .001$) and positively with pleasure from winning ($p < .01$). Furthermore, friendship closeness correlated negatively with negative friendship quality ($p < .001$) and positively with positive friendship quality ($p < .001$). There were no significant correlations at T2 between pleasure from winning and negative friendship quality and friendship closeness (*ps* > .23). At T3, pleasure from winning correlated positively with positive friendship quality ($p < .01$) and friendship closeness ($p = .01$). Friendship closeness further correlated positively with positive friendship quality ($p < .001$). Correlations of negative friendship quality with pleasure from winning, and of negative friendship quality with positive friendship quality and friendship closeness were not significant (*ps* > .32).

Table S1. Whole brain ANOVA

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
Ventral striatum	R	89	6.82	12	15	-3
	L	102	6.50	-9	15	-3
			5.83	-18	6	-9

Note. Family-wise error correction, $p < .05$, $k \geq 10$.

L = left, R = right.

Table S2. Correlation matrix

	Pleasure from winning	Negative friendship quality	Positive friendship quality
T1			
Pleasure from winning	-		
Negative friendship quality	-.11	-	
Positive friendship quality	.11	**-.36*** **	-
Friendship closeness	n/a	n/a	n/a
T2			
Pleasure from winning	-		
Negative friendship quality	-.12	-	
Positive friendship quality	**.25** **	**-.42*** **	-
Friendship closeness	.07	**-.27*** **	**.50*** **
T3			
Pleasure from winning	-		
Negative friendship quality	-.01	-	
Positive friendship quality	**.26** **	.10	-
Friendship closeness	**.24***	.01	**.53*** **

*Table shows Pearson's r. Significant coefficients are in bold, *p < .05, **, p < .01, *** p < .001.*
Note. Friendship closeness at T1 is not available (n/a).

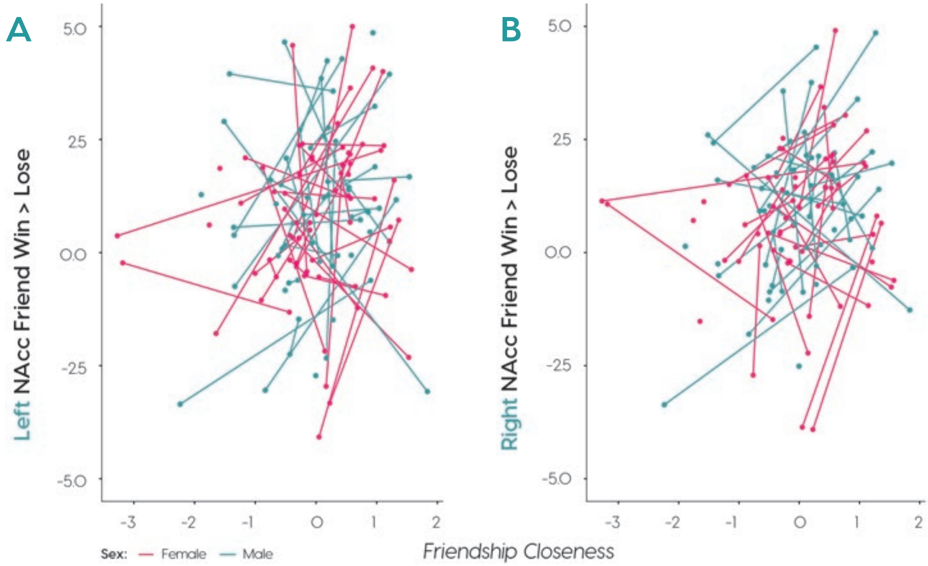


Figure S3. Raw data of the relation between vicarious reward-related NAcc activity and friendship closeness in adolescents with unstable best friendships. *A) the left NAcc, B) right NAcc.*

CHAPTER 4

Distribution of Behavior and Parameter Estimates

We did not exclude participants based on a minimum number of responses in a specific condition in the analyses. Table S1 provides an overview of how many participants had more than 0-5 trials in the contrasts discussed in the results section of chapter 4. To examine the robustness of our findings, we reran the whole brain contrasts Friend Prosocial > Disliked Peer Prosocial, Friend Prosocial > Unfamiliar Peer Prosocial, and Disliked Peer Selfish > Friend Selfish in which we excluded participants with only one trial. These results are described in chapter 4. In Figure S1 we show the distribution of parameter estimates from the clusters obtained in the Friend Prosocial > Disliked Peer Prosocial and Disliked Peer Selfish > Friend Selfish *t*-contrasts for each of the 27 participants. Importantly, Figure S1 shows that there were no outliers that could have driven our findings where all participants are included.

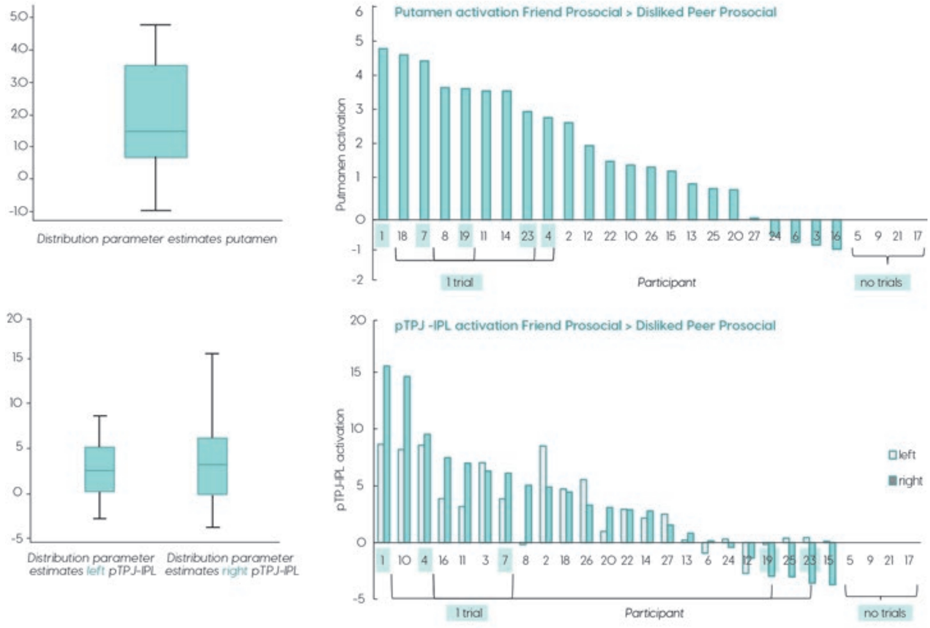
Table S1. Number of participants with more than 0-5 trials

	n > 0	*n* > 1	*n* > 2	*n* > 3	*n* > 4	*n* > 5
Friend Prosocial > Disliked Peer Prosocial	23	18	17	14	14	11
Friend Prosocial > Unfamiliar Peer Prosocial	23	23	22	20	19	19
Disliked Peer Selfish > Friend Selfish	26	24	23	22	21	20

Brain Regions of Activation during Interactions with Friends and Disliked Peers

First, we examined the neural underpinnings of decision-making for friends and disliked peers regardless of behavior. The whole brain one sample *t*-test of Friend > Disliked Peer (controlling for the frequency of prosocial behavior) did not yield significant clusters of brain activation. The Friend > Unfamiliar Peer contrast resulted in activation in the right inferior parietal lobule (IPL) extending towards the angular gyrus, and left IPL extending towards the superior parietal lobule. These brain regions are referred to as pTPJ-IPL. The whole brain *t*-contrasts of Disliked Peer > Friend, Disliked Peer > Unfamiliar Peer, Friend >

Friend Prosocial > Disliked Peer Prosocial



Disliked Peer Selfish > Friend Selfish

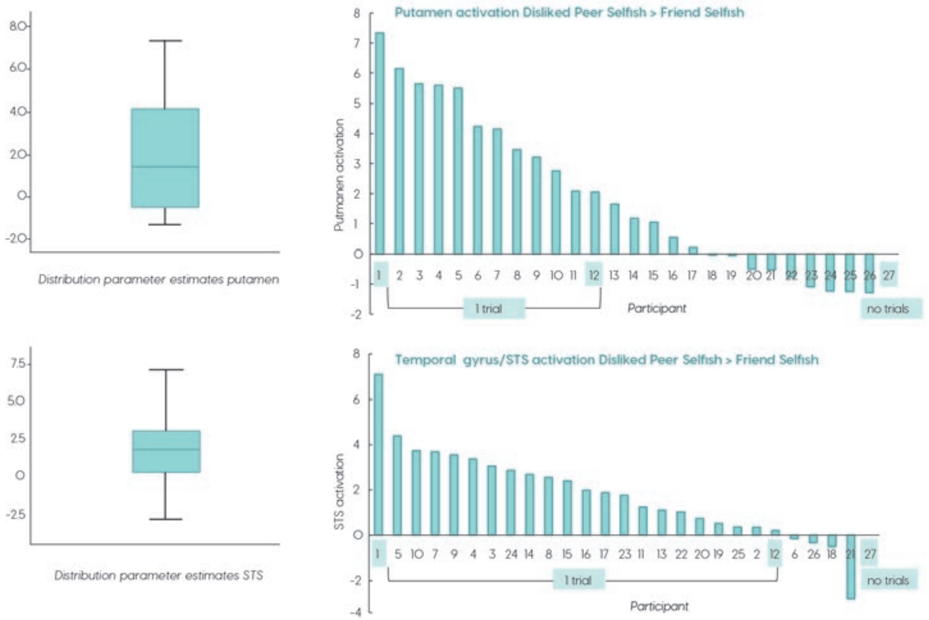


Figure S1. Distribution of activation clusters from the Friend Prosocial > Disliked Peer Prosocial and Disliked Peer Selfish > Friend Selfish t-contrasts for each of the 27 participants.

Neutral Peer, and Disliked Peer > Neutral Peer did not result in significant clusters of activity. The fact that there were no differences in neural activation for friends and disliked peers in the Friend > Disliked Peer and the reverse contrast were unexpected. Together with the results showing neural differences in the Friend Prosocial > Disliked Peer Prosocial and Disliked Peer Selfish > Friend Selfish contrasts, our findings suggest that at the neural level it is not the valence of the relationship with the interaction partner per se that affects the underlying neural processes differently, but rather the specific behavior for that interaction partner.

Next, we examined the neural correlates of prosocial and selfish decisions during interactions with friends and disliked peers. The whole brain one sample *t*-test for prosocial decisions for friends compared to neutral peers (Friend Prosocial > Neutral Peer Prosocial) controlled for the frequency of prosocial choices yielded heightened activation in the left inferior frontal gyrus (n = 24). The Friend Selfish > Neutral Peer Selfish contrast did not result in significant neural activation. The Disliked Peer Prosocial > Neutral Peer Prosocial, and Disliked Peer Selfish > Neutral Peer Selfish also did not yield significant increased brain activation.

Brain Regions of Activation during Decisions for Neutral Peers

We examined the neural correlates of decision making for neutral peers regardless of behavior. The Neutral Peer > Friend and Neutral Peer > Disliked peer *t*-contrasts did not yield significant activation clusters.

Next, we examined the neural correlates of prosocial and selfish decisions during interactions with neutral peers. The Neutral Peer Selfish > Friend Selfish contrast yielded activation in the left amygdala extending towards the temporal pole (n = 26). The Neutral Peer Prosocial > Friend Prosocial, Neutral Peer Prosocial > Disliked Peer Prosocial, and Neutral Peer Selfish > Disliked Peer Selfish contrasts did not yield significant heightened neural activation.

Table S2. Regions of neural activation

Brain Region	L/R	Voxels	z	MNI coordinates x	y	z
Friend > Unfamiliar Peer						
pTPJ-IPL	R	399	4.26	30	-54	36
			3.9	42	-60	51
			3.37	42	-54	39
pTPJ-IPL	L	196	3.77	-48	-51	42
			3.36	-24	-54	42
			2.97	-36	-39	33
Dorsal anterior cingulate cortex	-	269	4.24	-12	30	36
			4.19	18	33	21
			4	-21	36	27
Lateral prefontal cortex	L	150	4.14	-33	45	-9
			3.67	-18	57	-3
			3.47	-24	45	-3
Prosocial choices						
Friend > Neutral Peer						
Inferior frontal gyrus	L	149	4.48	-54	15	6
			3.02	-54	27	0
Selfish choices						
Neutral Peer > Friend						
Amygdala - Fusiform gyrus - Temporal pole	L	205	3.9	-24	-3	-24
			3.79	-30	0	-33
			3.54	-36	9	-33

Note. Analyses are conducted using FWE cluster-correction at $p < .05$ with a cluster-forming threshold of $p < .005$.

Brain Regions of Activation during Decisions for Unfamiliar Peers

We examined the neural underpinnings of decision-making for unfamiliar peers regardless of behavior. The Unfamiliar Peer > Disliked Peer contrast showed activation in the dorsal anterior cingulate cortex and the left lateral prefrontal cortex. The Unfamiliar Peer > Friend did not yield significant activation clusters.

Next, we conducted *t*-tests to examine neural activation for unfamiliar peers during prosocial and selfish choices. The Unfamiliar Peer Prosocial > Friend Prosocial, Unfamiliar Peer Prosocial > Disliked Peer Prosocial, Unfamiliar Peer Selfish > Friend Selfish, Unfamiliar Peer Selfish > Disliked Peer Selfish contrasts did not yield significant heightened brain activation for unfamiliar peers. Table S2 provides a summary of all the results.

Brain and Behavior Links for Friends and Disliked Peers versus Neutral Peers

The percentage of prosocial choices for friends minus neutral peers in the Friend > Neutral Peer contrast did not result in any significant or positive relations with brain activity. To investigate the brain and behavior links during interactions with disliked peers, we included the difference scores of the percentage of prosocial choices for disliked peers minus neutral peers as a regressor in the Disliked Peer > Neutral Peer *t*-contrast. This showed a negative correlation between the frequency of prosocial choices for disliked peers minus neutral peers and an activation cluster in the left inferior frontal gyrus. Correlation coefficients indicated that this negative relation was driven by individual differences in prosocial choices for disliked peers rather than for neutral peers (correlation coefficients of the relation between the parameter estimates of the interior frontal gyrus and the percentage of prosocial choices for disliked peers and neutral peers separately were -.57 and .08, respectively). This analysis did not yield a positive correlation between brain and behavior links for disliked peers versus neutral peers. Table S3 provides a detailed overview of these results.

Table S3. Regions of neural activation

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
Disliked Peer > Neutral Peer						
Inferior frontal gyrus	L	119	4.33	-54	9	18
			3.13	-54	0	21
			2.92	-51	30	18

Mean prosocial choices for disliked peers-neutral peers as negative regressor.

Note. Analyses are conducted using FWE cluster-correction at $p < .05$ with a cluster-forming threshold of $p < .005$.

CHAPTER 5

In the Supplementary materials we report results in which decisions for friends and disliked peers are contrasted with neutral peers. We further show results for contrasts that are collapsed by choice, and that were aimed to examine decision-making for neutral and unfamiliar peers. Table S1 lists these neuroimaging results.

Additionally, Table S2 and Table S3 provide an overview of the number of participants and the neuroimaging results of the analyses we conducted to test the robustness of the results for the Friend Prosocial > Disliked Peer Prosocial, Friend Prosocial > Unfamiliar Peer Prosocial, and Friend Prosocial > Neutral Peer Prosocial contrasts. We tested whether the neuroimaging results were similar as the results reported in chapter 5 when only participants were included with more than 1, 2, 3, and 4 prosocial responses in the conditions from the contrast. Overall, these additional analyses yielded similar results.

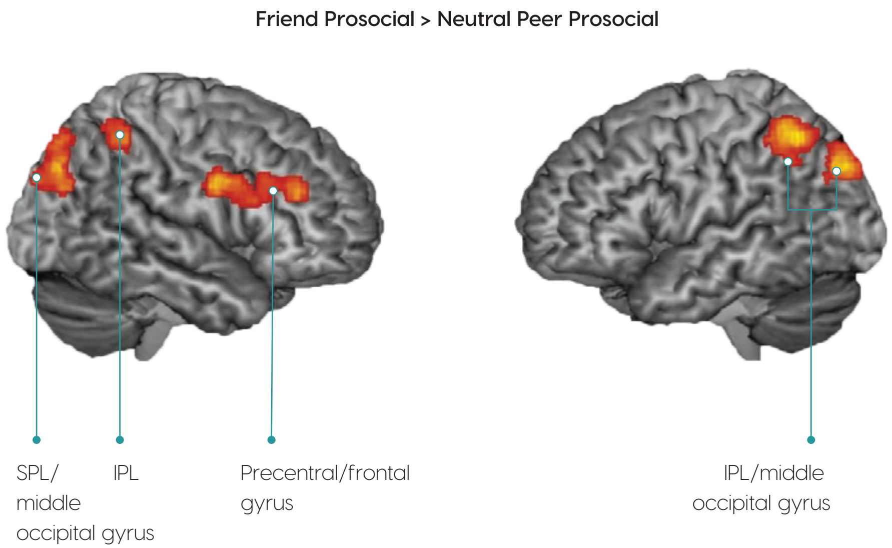


Figure S1. Whole brain contrast controlling for the frequency of prosocial behavior for Friend Prosocial > Neutral Peer Prosocial. *Right SPL/middle occipital gyrus (33, -76, 34), right IPL (42, -45, 51), right precentral/frontal gyrus (47, 3, 32), and left IPL/middle occipital gyrus (-3, -78, 37). SPL = superior parietal lobule, IPL = inferior parietal lobule.*

Neuroimaging Results for Social Decisions for Friends and Disliked Peers versus Neutral Peers (Collapsed over Choice)

Decision-making with friends

First, we examined the Friend Prosocial > Neutral Peer Prosocial (*n* = 47) contrast (controlled for the proportion of prosocial choices), which resulted in increased activation in right precentral-frontal gyrus, and bilateral clusters in inferior parietal lobule (IPL)-middle occipital gyrus (Figure S1).

Next, we investigated neural activation patterns in interactions with friends and disliked peers irrespective of choice and controlled for the frequency of prosocial choices (*n* = 50). The whole brain one-sample *t*-test of Friend > Disliked Peer revealed activation in left IPL extending toward the angular gyrus, and activation in the middle cingulate cortex, and the postcentral gyrus (Figure S2A). The Friend > Unfamiliar Peer *t*-test resulted in activation in the left IPL, the right SPL, the right middle frontal gyrus, left precentral gyrus, and the superior medial prefrontal gyrus (Figure S2B). The whole brain one sample t-test for decision-making for friends compared to neutral peers (Friend > Neutral Peer) yielded heightened activation in the left IPL, right SPL, and bilateral inferior frontal gyrus (IFG; Figure S2C). Table S1 provides a detailed list with the results.

Decision-making with disliked peers

The Disliked Peer > Friend, Disliked Peer > Unfamiliar Peer, Disliked Peer > Neutral Peer, Disliked Peer Prosocial > Neutral Peer Prosocial, and Disliked Peer Selfish > Neutral Peer Selfish did not yield significant increased brain activation at our chosen threshold.

Table S1. Anatomical labels of neural activation

Brain Region	L/R	Voxels	z	MNI coordinates x	y	z
Friend Prosocial > Neutral Peer Prosocial						
Middle occipital gyrus	L	436	4.40	-34	-78	37
Inferior parietal lobule			4.40	-40	-53	51
Middle occipital gyrus			3.82	-34	-67	29
Middle occipital gyrus	R	196	4.16	33	-76	34
Superior parietal lobule			3.72	25	-78	48
Middle occipital gyrus			3.60	33	-87	29
Inferior parietal lobule	R	116	3.76	42	-45	51
Inferior parietal lobule			3.72	33	-48	46
-			3.56	28	-45	40
Precentral gyrus	R	261	4.38	47	3	32
Middle frontal gyrus			4.05	39	39	26
Inferior frontal gyrus			3.57	61	22	23
Friend > Disliked Peer						
Inferior parietal cortex	L	156	4.20	-31	-87	37
Inferior parietal cortex			3.61	-45	-78	32
Angular gyrus			3.41	-42	-53	29
Postcentral gyrus	R	108	4.03	28	-42	68
Precentral gyrus			3.45	28	-28	71
Middle cingulate cortex	-	242	4.6	-12	0	40
-			3.89	-23	11	40
SMA			3.88	2	-11	60
Middle cingulate cortex	-	173	3.87	-6	-28	43
Middle cingulate cortex			3.78	-3	-42	43
Paracentral lobule			3.63	-9	-34	51

Table S1. Continued

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
Friend > Unfamiliar Peer						
Middle frontal gyrus	R	124	4.34	47	53	6
Middle frontal gyrus	R	149	3.72	47	36	37
Middle frontal gyrus			3.63	47	48	26
Inferior frontal gyrus			3.59	42	31	26
Superior medial (prefrontal) cortex	-	94	3.71	5	62	20
Superior medial (prefrontal) gyrus			3.51	-3	48	32
Superior medial (prefrontal) gyrus			3.38	-12	42	34
Precentral gyrus	L	528	4.85	-51	0	37
Middle frontal gyrus			3.67	-28	6	51
Precentral gyrus			3.56	-34	-6	57
-	R	421	4.62	30	-50	43
Superior parietal lobule			4.35	39	-56	54
Superior parietal lobule			4.09	53	-39	60
Inferior parietal lobule	L	500	4.26	-42	-56	57
Superior parietal lobule			4.06	-20	-70	54
-			4.01	-54	-50	54
-			3.49	-48	-50	48
Friend > Neutral Peer						
Inferior frontal gyrus	R	137	4.33	50	42	-5
Middle orbital gyrus			3.50	39	50	-10
Inferior frontal gyrus	L	124	3.80	-51	45	6
Inferior frontal gyrus			3.80	-48	39	-2
-	R	256	4.13	30	-48	43
Superior parietal lobule			3.85	33	-70	48

Table S1. Continued

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
Friend > Neutral Peer (continued)						
Middle occipital gyrus			3.59	33	-76	32
Inferior parietal lobule	L	233	3.96	-34	-59	51
Inferior parietal lobule			3.49	-48	-50	48
Unfamiliar Peer Prosocial > Disliked Peer Prosocial						
Middle temporal gyrus	L	90	4.74	-62	-8	-10
Superior temporal gyrus			4.51	-59	-11	1
Postcentral gyrus	R	100	4.19	36	-22	48
Postcentral gyrus			3.91	44	-25	57
Postcentral gyrus			3.50	47	-20	48
Neutral Peer Selfish > Friend Selfish						
Precuneus	-	357	3.88	11	-67	29
Cuneus			3.68	-12	-73	20
Cuneus			3.51	-12	-76	32
Precentral gyrus	L	111	3.43	-40	-20	57
Precentral gyrus			3.40	-31	-28	57
Postcentral gyrus			3.32	-48	-31	54
Neutral Peer Selfish > Disliked Peer Selfish						
Calcarine gyrus	L	99	4.57	-12	-56	9
Cuneus			3.33	-9	-67	26

Anatomical labels of neural activity from whole brain contrasts for (prosocial and selfish) choices for friends, neutral peers, and unfamiliar peers. Unindented regions are the peak cluster, and indented regions are subclusters. L = left, R = right.

Note. Analyses are conducted at the threshold of $p < .001$ FWE cluster-extent based corrected.

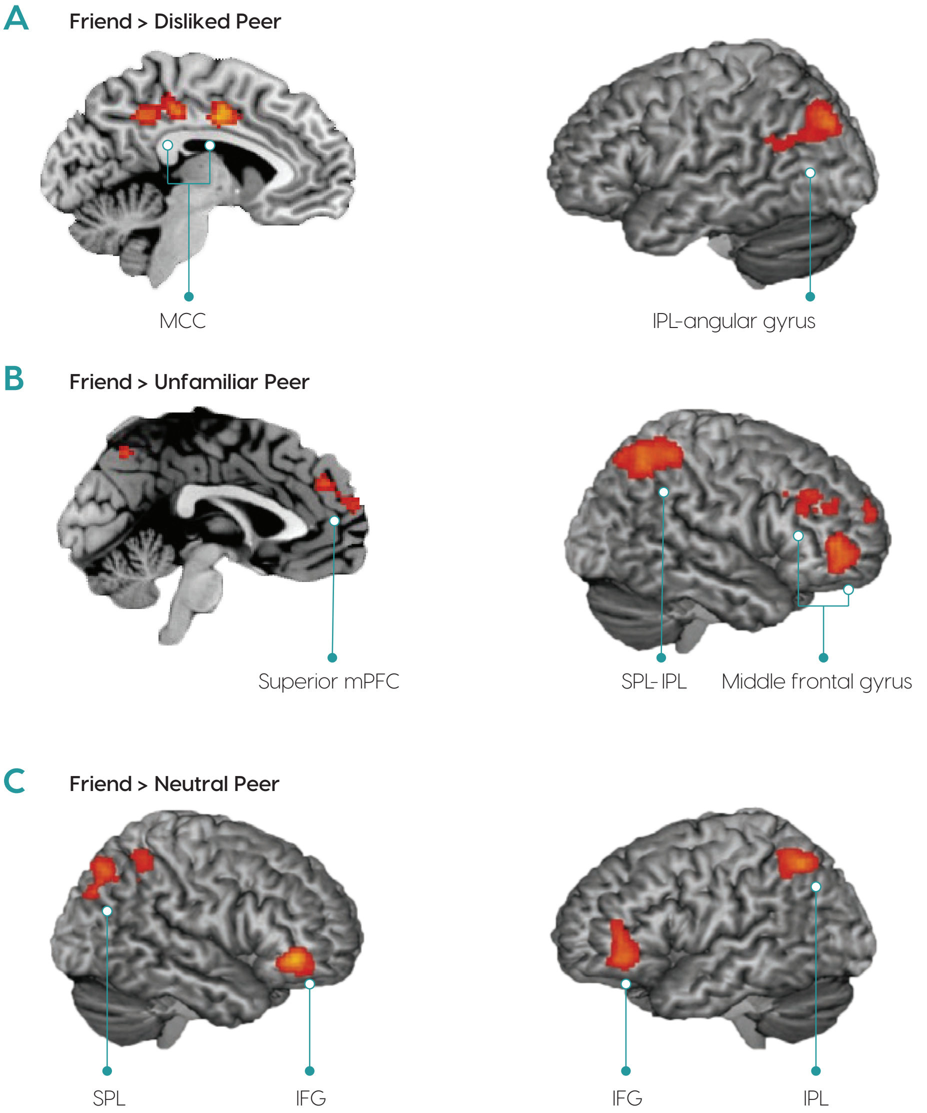


Figure S2. Whole brain contrasts controlling for the frequency of prosocial behavior of (A) Friend > Disliked Peer, (B) Friend > Unfamiliar Peer, and (C) Friend > Neutral Peer contrasts. *(A) resulted in activation in MCC (-12, 0, 40; -6, -28, 43) the IPL-angular gyrus (-31, -87, 37), (B) resulted in activation in superior mPFC (5, 62, 20), middle frontal gyrus (47, 36, 37; 47, 53, 6), and (C) resulted in activation in the right SPL (30, -48,43), right IFG (50,42, -5), left IFG (-51, 45, 6), and left IPL (-34, -59, 51). MCC = middle cingulate cortex, IPL = inferior parietal lobule, SPL = superior parietal lobule, mPFC = medial prefontal cortex, IFG = inferior frontal gyrus.*

Neuroimaging Results for Decisions for Neutral Peers and Unfamiliar Peers versus Friends and Disliked Peers

Collapsed over choice

The Neutral Peer > Friend, and the Neutral Peer > Disliked Peer did not yield significant increased brain activation. The Unfamiliar Peer > Friend and Unfamiliar Peer > Disliked Peer did not yield significant heightened brain activation for unfamiliar peers (all *n*s = 50).

Prosocial choices

The Neutral Peer Prosocial > Friend Prosocial (*n* = 47), Neutral Peer Prosocial > Disliked Peer Prosocial (*n* = 47), and Unfamiliar Peer Prosocial > Friend Prosocial (*n* = 47) did not yield significant clusters of brain activity. The Unfamiliar Peer Prosocial > Disliked Peer Prosocial (*n* = 47) whole brain *t*-test (controlled for the frequency of prosocial choices) yielded activation in the right postcentral gyrus and the middle temporal -superior temporal gyrus (Table S1).

Selfish choices

The Neutral Peer Selfish > Friend Selfish (*n* = 40) resulted in (pre)cuneus and precentral gyrus activity. The Neutral Peer Selfish > Disliked Peer selfish (*n* = 47) resulted in activity in the cuneus-calcarine gyrus (Table S1). The Unfamiliar Peer Selfish > Friend Selfish (*n* = 40) and Unfamiliar Peer Selfish > Disliked Peer Selfish (*n* = 47) *t*-tests did not yield heightened brain activation.

Robustness Neuroimaging Results during Prosocial Choices for Friends

We tested the robustness of the results from the Friend Prosocial > Disliked Peer Prosocial, Friend Prosocial > Unfamiliar Peer Prosocial, and Friend Prosocial > Neutral Peer Prosocial contrasts reported in chapter 5. We reran the analyses 4 more times where we only included participants with more than 1, 2, 3, and 4 prosocial responses, respectively, in the conditions contrasted. As can be seen in Table S2, most participants were lost in the Friend Prosocial > Disliked Peer Prosocial contrast as compared with the Friend Prosocial > Unfamiliar Peer Prosocial and Friend Prosocial > Neutral Peer Prosocial contrasts when only including participants with more than 1, 2, 3, or 4 prosocial responses for friends or disliked peers. This can be expected, since on average participants made least prosocial choices for disliked peers.

Table S2. Number of participants

	n participants		
n trials	Friend Prosocial > Disliked Peer Prosocial	Friend Prosocial > Unfamiliar Peer Prosocial	Friend Prosocial > Neutral Peer Prosocial
> 1	43	45	46
> 2	40	44	44
> 3	39	43	44
> 4	36	41	44

The additional tests confirmed the activation of the putamen in the Friend Prosocial > Disliked Peer Prosocial contrast when only participants with more than 1, 2 and 3 prosocial responses for friends and disliked peers were included; enhanced putamen activity was not found when only participants were included with more than 4 prosocial choices in both conditions.

For the Friend Prosocial > Unfamiliar Peer Prosocial contrast heightened activity in the SPL was obtained in all analyses (i.e., when analyses were rerun including only participants with more than 1, 2, 3 and 4 trials in both conditions). Precentral gyrus activity was replicated only when participants were included with more than 4 responses in both conditions, but not in the other reanalyses. Finally, for the Friend Prosocial > Neutral Peer Prosocial contrast, the left IPL and right middle occipital gyrus-SPL activation patterns were replicated in all 4 reanalyses, but right precentral-middle frontal gyrus and right IPL activity were not. To briefly report these results, the analyses including only participants with more than 3 or 4 prosocial responses in the conditions of interest are reported in Table S3.

Table S3. Testing robustness of prosocial choices for friend versus other peer contrasts*

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
> 3 responses						
Friend Prosocial > Disliked Peer Prosocial						
Middle cingulate cortex	L	450	5.03	-12	0	40
Postcentral gyrus			4.50	30	-42	65
Superior parietal lobule			4.22	16	-53	62
Pallidum	R	112	4.53	28	-8	1
Putamen			3.72	33	-20	1
Insula			3.42	42	-11	-13
Friend Prosocial > Unfamiliar Peer Prosocial						
Superior parietal lobule	R	121	4.28	42	-50	57
Superior parietal lobule			3.44	28	-67	51
> 4 responses						
Friend Prosocial > Disliked Peer Prosocial						
Postcentral gyrus	R	106	4.19	28	-45	65
Superior parietal lobule			3.84	16	-53	62
Friend Prosocial > Unfamiliar Peer Prosocial						
Precentral gyrus	L	124	4.46	-48	0	37
-			3.58	-28	-3	40
Superior parietal lobule	R	150	4.22	39	-50	57
Superior parietal lobule			3.60	28	-67	51
Inferior parietal lobule			3.51	36	-48	46
Superior parietal lobule	L	126	3.88	-23	-70	57
Inferior parietal lobule			3.50	-26	-67	43
Superior occipital gyrus			3.19	-23	-84	46
> 3-4 responses						

Table S3. Continued

Brain Region	L/R	Voxels	z	MNI coordinates		
				x	y	z
Friend Prosocial > Neutral Peer Prosocial						
Middle occipital gyrus	R	122	4.06	33	-76	32
Middle occipital gyrus			3.75	33	-87	29
Superior parietal lobule			3.30	28	-76	48
Inferior parietal lobule	L	115	3.98	-40	-53	54

Note. Analyses are conducted at the threshold of $p < .001$ FWE cluster-extent based corrected. L = left, R = right.

* contrasts including only participants with more than 3 or 4 trials in each condition. Unindented regions are the peak cluster, and indented regions are subclusters.

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CURRICULUM VITAE

Elisabeth (Lisa) Schreuders was born on 4 November 1990 in 's-Gravenhage, The Netherlands. After graduating from high school (Dalton Den Haag) in 2009, Lisa obtained her Bachelor of Science in Psychology in 2012 and her (Research) Master of Science in Cognitive Neuroscience in 2014 at Leiden University. Lisa started her PhD project in the Brain and Development Research Center at Leiden University in January 2015 under joint supervision of Prof. Dr. Berna Güroğlu and Prof. Dr. Eveline Crone. During her PhD, Lisa studied links between peer relationships and adolescent brain development. After completion of her PhD research, Lisa started working as a postdoctoral researcher in the Department of Developmental Psychology at Tilburg University. As a post-doctoral researcher she continues studying how peer relationships contribute to adolescent development from a neuroscience perspective.