Social behavior in young twins : are fearfulness, prosocial and aggressive behavior related to frontal asymmetry?

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CHAPTER 4

Social judgments, frontal asymmetry, and aggressive behavior in young children: A replication study using EEG

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Abstract

Early in their lives young children are confronted with social judgments by peers. Previous studies have shown that in adults negative social judgments are associated with more aggressive behavior. However, little is known about the relation between social judgments and aggressive behavior, or the underlying neurocognitive mechanisms, in early childhood. We developed the Social Network Aggression Task - Early Childhood (SNAT-EC) to examine the mediating role of frontal EEG asymmetry in the relation between social judgment and aggressive behavior in 4–6 year old children. To replicate our findings, we included three samples: a pilot sample, test sample 1 and test sample 2 (total N =78). In the SNAT-EC, children receive positive, negative and neutral social judgments about their chosen cuddly animal by same-aged unfamiliar peers. EEG was acquired to measure frontal asymmetry during the processing of social judgments. Aggressive behavior was measured as the duration of a button press with which children could destroy balloons of the judging peer, thus reducing the number of remaining balloons for that peer. We used a within-subject mediation model to test whether frontal asymmetry mediated the effect of social judgment (negative vs. positive) on aggressive behavior. Results show that the SNAT-EC robustly elicits more aggressive behavior in response to negative social judgments about the cuddly animal compared to positive judgments. Meta-analysis revealed a large combined effect size ($r = .42$) for the relation between negative (vs. positive) social judgments and aggressive behavior. However, frontal asymmetry in response to the social judgments did not mediate the relation between social judgment and aggressive behavior. Future studies should search for other neural mediators to bridge the brain-behavior gap between social judgments and aggressive behavior, in particular in early childhood.

Keywords: Social judgments, aggression, frontal EEG asymmetry, early childhood, replication

Introduction

From early childhood onwards, children are confronted with social judgments from peers that imply social acceptance or rejection (Coie et al., 1982). According to the social belongingness hypothesis (Baumeister and Leary, 1995), social acceptance is important for humans, and experiencing negative social judgments at a young age has a great impact on mental health and stress levels later in life (Lereya et al., 2015; Newman et al., 2010). In addition, a longitudinal study using sociometric interviews and teacher reports showed that peer rejection is associated with an increase in aggressive behavior in schoolage children (Dodge et al., 2003). A study by Buckley and colleagues (2004) further highlights the role of negative emotions. These authors showed that receiving negative social judgments evokes negative emotional feelings, such as anger and sadness, that in turn can lead to aggressive behavior (Buckley et al., 2004). However, the direct effects of social judgments on aggression in early childhood have not yet been examined with experimental paradigms. It is important to investigate such direct effects to determine whether negative social judgments immediately cause aggression. Also, using appropriate measures, experiments can provide important insights into the underlying neurocognitive mechanisms that mediate a relation between social judgment and aggressive behavior. The current study investigated the neural and behavioral responses to positive, negative and neutral social judgments in 4- to 6-year-old children with the newly developed Social Network Aggression Task for Early Childhood (SNAT-EC).

The neural mechanisms involved in the processing of social judgments can be investigated using the social judgment paradigm from Somerville and colleagues (Somerville et al., 2006). In this task, participants are expectedly or unexpectedly accepted or rejected by peers. Imaging studies of social judgment processing in adult participants provided some insights into the brain structures involved in processing social rejection (a.o., vACC, striatum, several regions of prefrontal cortex regions (Gunther Moor et al., 2010; Somerville et al., 2006)). The processing of social judgments is further investigated in adults (Achterberg et al., 2016) and 7–10 year old children (Achterberg et al., 2017) by adding a behavioral response: participants could blast a loud noise to the judging peer after receiving a social judgment. Participants reacted more aggressively by blasting louder noises after receiving a negative social judgment than after a neutral or positive social judgment (Achterberg et al., 2016). However, the authors did not test whether effects of social judgments on brain activity mediated effects on aggressive behavior. Thus it remained unclear whether neural activity in response to negative judgments explains aggressive behavior, especially in early childhood.

Here we study asymmetric frontal cortical activity as a potential neural mechanism of aggressive behavior in response to social judgments in early childhood. Asymmetric frontal cortical activity reflects the difference in activity of the left and right frontal hemispheres and can be measured using electroencephalography (EEG). Because higher power in the EEG alpha band reflects deactivation of cortical tissue (Cook et al., 1998; Laufs et al., 2003), higher alpha power over the left than over the right frontal cortex reflects relatively greater activity of the right frontal areas. Conversely, higher alpha power over the right than the left frontal cortex reflects relatively greater activity of the left frontal cortex. The motivational direction model explains frontal asymmetries in terms of approach-withdrawal motivation (Harmon-Jones et al., 2010). Relatively greater left frontal brain activity reflects a tendency toward approach behavior and relatively greater right frontal brain activity reflects a tendency toward withdrawal behavior. For example, feelings of aggression, an approach–related emotion, have been associated with greater left than right frontal brain activity (Harmon-Jones, 2004, 2007; Harmon-Jones and Allen, 1998; see also Harmon-Jones et al., 2010).

Both trait levels as well as state-related variations in approach-withdrawal motivation contribute to measures of frontal asymmetry (Coan and Allen, 2004). Condition differences in frontal asymmetry, as well as changes relative to a baseline measure can be used to track state-related fluctuations (Hagemann et al., 2005; Harmon-Jones and Sigelman, 2001; Verona et al., 2009). For example, Harmon-Jones and Sigelman (2001) found that anger provoking insults from peers resulted in relatively greater left frontal activity. To measure aggressive behavior in response to these insults, participants could administer unpleasant beverages like vinegar or hot sauce mixed with water to the insulting peers. The authors found that participants who showed more aggressive behavior after an insult also showed greater relative left frontal activity (Harmon-Jones and Sigelman, 2001). Such studies suggest that greater relative left frontal activity may mediate the association between anger evoking stimuli and aggressive behavioral reactions. In fact, frontal asymmetry has been suggested as a likely mediator of behavioral responses more generally: the effect of a stimulus on behavior is suggested to come about through frontal asymmetry and associated approach or withdrawal motivation (Coan and Allen, 2004). However, to the best of our knowledge, the mediating role of frontal asymmetry in responses to different stimuli in a within-subject design has not been examined yet.

In sum, previous studies including older children and adults have suggested that there are relations between social judgment, aggressive behavior and neural activity: negative social judgments lead to more aggressive behavior and several brain regions seem involved in processing social judgments (a.o., vACC, striatum, several regions of prefrontal cortex regions (Achterberg et al., 2016, 2017; Gunther Moor et al., 2010; Somerville et al., 2006)). However, whether these relations are already present in early childhood remains unknown. Moreover, as far as we know, no study to date has directly assessed whether neural processes mediate effects of social judgments on aggressive behavior. The association of relative left frontal asymmetry with approach motivation and feelings of anger and aggression (e.g., Harmon-Jones et al., 2010; Harmon-Jones and Sigelman, 2001) make it a likely candidate. The current study therefore examines whether frontal asymmetry in response to social judgments mediates the relation between social judgments and aggressive behavior in 4–6 year-old children. For this purpose, we developed the Social Network Aggression Task – Early Childhood (SNAT-EC) in which children received positive, neutral, and negative social judgments from same-aged unfamiliar peers. To measure aggressive behavior, in response to these social judgments, children could destroy balloons of the judging peer by pressing a button. The duration of the button press, reflecting the number of balloons destroyed, was used as the measure of aggression.

To test the validity of our task and the replicability of the outcomes (Collaboration, 2015; Pashler and Wagenmakers, 2012), we used three different samples: a pilot sample, test sample 1 and test sample 2. The pilot sample was independent from the two test samples. The two test samples consisted of same-sex twin pairs. Each co-twin was randomly assigned to either test sample 1 or test sample 2. Finally, we combined the results from each sample in a meta-analysis.

Based on previous findings (Achterberg et al., 2016; Dodge et al., 2003) we expected that children would react more aggressively after a negative social judgment compared to a positive or neutral social judgment. Furthermore, we hypothesized that the effects of social judgment on aggressive behavior would be mediated by frontal asymmetry: we expected that greater left frontal brain activity in response to negative social judgments would explain increased aggression after these judgments. Last, we expected to replicate the results from the pilot sample in the two test samples.

Materials and methods

Participants

The pilot sample included 13 opposite-sex twin pairs and 24 singletons, aged 4–7 years. Singletons were recruited at two elementary schools in the Leiden area. Opposite-sex twins were recruited via municipal authorities in the western part of the Netherlands. The two test samples included 50 same-sex twin pairs, aged 4–5 years, and consisted of the first 50 families who participated in the larger, longitudinal study of the Leiden Consortium on Individual Development (L-CID; Euser et al., 2016)). The families with same-sex twins were recruited via municipal authorities in the western part of the Netherlands. Twins and their parents were included if they were fluent in Dutch. Exclusion criteria for all participants were known disabilities or neurological impairments (e.g. congenital disability, psychological disorder, chronic illness, hereditary disease, or a visual or hearing impairment). Each co-twin was randomly assigned to either test sample 1 or test sample 2.

Some participants were excluded from the analysis due to insufficient artifact-free EEG data, too many invalid behavioral trials, technical problems or not enough trials seen (pilot N = 17, test sample 1 N = 15, test sample 2 N = 13). In addition, some children refused to wear the EEG-net (pilot N = 10; test sample 1 N = 11, test sample 2 N = 9). Characteristics of the included and excluded participants are shown in Table 1. The final pilot sample consisted of 21 children (8 girls, M = 6.02 years, SD = .73, 17 single children and 4 twin children), the final test sample 1 consisted of 27 children (16 girls, M = 5.16 years, SD = .38) and the final test sample 2 consisted of 30 children (14 girls, M = 5.12 years, SD = .45). The difference between included and excluded children was only significant for age in the pilot sample (pilot sample: t (48) = 7.03, p<.01; test sample 1: t (48) = 1.72, p = .09; test sample 2: t (48) = 1.27, p = .21). No significant gender differences were found between included and excluded children (pilot sample: X2 (1, N = 50) = .51, p = .47; test sample 1: X2 (1, N = 50) = .65, p = .42; test sample 2: X2 (1, N = 50) = 1.62, p = .20).

Participating children received a small gift and the caregiver received a financial reimbursement. Written informed consent was obtained from both caregivers. Study procedures were approved by the local ethics committee and the Central Committee on Research Involving Human Subjects in the Netherlands.

Procedure

The lab visit consisted of electroencephalogram (EEG) measures during the Social Network Aggression Task – Early Childhood (SNAT-EC), a baseline EEG measurement, and several behavioral tasks (results presented elsewhere). Twins were invited to the lab together; each co-twin was randomly assigned to the EEG block or the behavioral block as their first task. At the start of the EEG block the experimenter explained the EEG procedure to the parent and the child. Next, the child was fitted with an electrode net. After a 3-min resting (non-emotional) baseline EEG measurement the SNAT-EC was explained to the child. Participants were instructed how to destroy the balloons with a button press. Then the experimenter

Table 1. Characteristics of the samples.

	Pilot	Test 1	Test 2
Final Sample			
N	21	27	30
% girls	38%	59%	47%
Mean age in years (SD)	6.02 (.73)[a]	5.16 (.38)	5.12 (.45)
Age range	4.51 - 7.04	4.36 - 5.65	4.28 - 5.68
Excluded from sample			
N	29	23	20
% girls	48%	48%	65%
Mean age in years (SD)	4.77 (.54)[a]	4.95 (.48)	4.97 (.41)
Age range	4.21 – 6.41	4.28 – 5.68	4.36 – 5.50
Excluded due to (N):			
Refusing EEG-net	10	11	9
Technical problems	3	7	6
Invalid behavioral trials	5	4	3
Eyes off-screen (>50%)	4	-	-
EEG artifacts	7	1	2

[a] An age difference between final and excluded sample was found (t(48)=7.03, $p < .01$)

explained each social judgment to the child. To make sure that the child understood the judgments, we asked the child to repeat the meaning of each judgment. After 6 practice trials the SNAT-EC began. The total duration of the SNAT-EC was approximately 20 min after which the EEG recording was stopped. To motivate the children during the EEG measurement children received three stamps on a card: one after putting on the EEG net, one during a break (after 30 trials), and one at the end of the task.

Social Network Aggression Task – Early Childhood

To measure behavioral and neural responses to social judgments, we used an adapted version of the social evaluation paradigm developed by Somerville and colleagues (Somerville et al., 2006), which we called the Social Network Aggression Task – Early Childhood (SNAT-EC). In our version, children were not judged on personal characteristics but on a cuddly animal they had chosen as their favorite (see below). From an ethical perspective, rejection of the cuddly animal was preferred to rejection of the child him-/herself. In the SNAT-EC children could destroy balloons of the peer who had judged their cuddly animal as a measure of aggressive behavior.

Three weeks prior to the lab visit the children were asked via an e-mail to the primary caregiver to choose one out of five (pilot group) or four (test groups)[11] cuddly animals (see Fig. 1A). The cuddly animal was sent to the children's home two weeks before the lab visit to give the children time to get attached to the cuddly animal. During the lab visit participants were told a cover story explaining that other peers had judged their cuddly animal. Peers' feedback on the cuddly animal could be positive ("I like your cuddly animal"), negative ("Your cuddly animal is stupid") or neutral ("I don't know whether I like your cuddly animal"). In addition, participants were told that each peer had ten balloons. After receiving each peer's feedback on the computer screen, the participants could destroy the peers' balloons by pressing a button. The longer they pressed the button, the more balloons would be destroyed. Before the task started we explained to the participants that they had to press the button on each trial and that they should press the button very briefly if they did not want to destroy any balloons. The button press was practiced in 6 training trials during which the participants received feedback from the experimenter if necessary.

Feedback stimuli combined a judgment with a picture of the peer that supposedly provided the judgment. The pictures of the judging peers were created by morphing photographs of children to create a picture of a non-existing child matching with the age of the participants. This way, there was no chance that the participant would recognize a judging peer. Photographs were taken from young children at primary schools in two cities in the Netherlands. These photographs were morphed (using Abrosoft FantaMorph, version 5) with photographs of children from a database of Leiden University and Nijmegen University

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[1] Based on our experience from the pilot study we decided to let the children choose one out of four cuddly animals instead of five, because some cuddly animals were more popular than others and this way we could change the collection when one cuddly animal was out of stock.

(Langner et al., 2010). Pictures (20 × 28 mm) were placed inside a figure of a green thumb up (42 × 51 mm, positive), a red thumb down (42 × 51 mm, negative) or a grey oval (42 × 47 mm, neutral), resulting in 20 positive, 20 negative, and 20 neutral feedback stimuli respectively (see Fig. 1B). Stimuli were matched for luminance. Gender of the judging peers was equally divided over the three feedback types and during the task the judgments were presented in pseudorandom order with the restriction that the positive and neutral judgments could not be presented more than four times in a row and a negative judgment was never followed by another negative judgment.

For the pilot group the SNAT-EC was divided into two parts: the first part consisted of 90 observation trials (in which the child could not respond to the judgments) and the second part consisted of 60 action trials in which the participants could destroy the peer's balloons after seeing the judgment. After the pilot study we decided to shorten the task by leaving out the 90 observation trials to improve data quality during the action trials. For all samples the 60 action trials were used for data-analysis.

Each trial started with a fixation cross with a jittered duration of 500–1500 ms followed by a social judgment (positive and negative: 4.00 × 4.86° visual angle; neutral: 4.00 × 4.48° visual angle) for 4000 ms in the pilot group and for 2000 ms in the test groups[2], see Fig. 1C. Then another fixation cross was presented (duration 500–1500 ms, varying randomly) and thereafter a picture showing ten balloons (7.13 × 7.59° visual angle) appeared on the screen. Participants could destroy the balloons by pressing a button that was placed in front of the participant. After each 400 ms one balloon popped with a maximum of 9 balloons (4000 ms). Participants were instructed to start pressing the button as soon as possible and to release the button when they destroyed the number of balloons they wanted to destroy. To make sure each trial had the same duration, the image showing the remaining balloons stayed on screen for the remainder of the 4000 ms period after participants released the button. After

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[2] We used the pilot group to test for potential effects of stimulus duration on frontal asymmetry. Because frontal asymmetry over 4000 ms did not differ from frontal asymmetry over 2000 ms, we decided to shorten stimulus presentation in the test groups.

every 10 trials the participants had a 10-second break. After 30 trials there was a longer break (approximately 1 min).

Behavioral data for each subject was obtained by computing the mean pressing time per condition. Trials on which the participant did not press the button or failed to press it within 2000 ms were excluded. Eight trials per condition was considered a minimum to compute the mean pressing time.

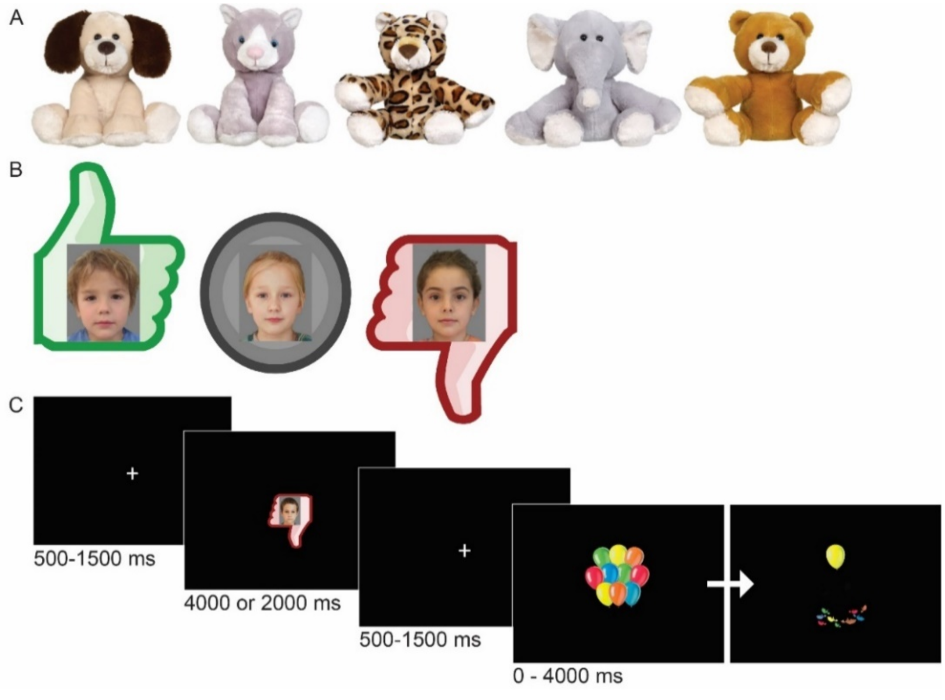

Figure 1. Social Network Aggression Task – Early Childhood (SNAT-EC). A) Selection of five cuddly animals from which each child chose one. B) The social judgments: positive, neutral and negative. C) Trial procedure of SNAT-EC.

EEG recordings

The EEG was recorded using a 64-channel hydrocel geodesic sensor net and NetStation software (Electrical Geodesics, Inc.). As it is important to minimize preparation time (each electrode needs to be adjusted to ensure a good connection) in order to avoid fatigue, irritability and a loss of attention in young children we decided to collect data from only a subset of the electrodes (number in brackets): F3 [12], F4 [60], F7 [18], F8 [8], C3 [20], C4 [50], T7 [24], T8 [52], P3 [28], P4 [42], P7 [30], P8 [44], left [29] and right [47] mastoids, and two electrodes [62, 63] placed directly below the eyes. The EEG signal was amplified with a NetAmps300 amplifier. The online reference was Cz, and data were low-pass filtered at the Nyquist frequency (i.e., 100 Hz) for the sampling rate of 250 Hz. Impedances were kept below 100 kΩ.

EEG data processing

To monitor attention to the screen during the task, a video camera was placed above the computer screen focusing on the face of the child. Segments in which the child did not look at the screen were marked and not included in the EEG analyses. Participants who saw less than 50% of the social judgments (< 30 trials) were excluded from further analysis. After applying a .3 Hz high-pass filter (99.9% pass-band gain, .1% stopband gain, 1.5 Hz roll-off) EEG data were exported for further processing with Brain Vision Analyzer (BVA) 2.0 software (Brain Products, Inc). Offline, the EEG signal was filtered with a 30 Hz low-pass filter (−3 dB, 48 dB/octave). The event of interest was the presentation of the social judgment (2000 ms). Segments extending from 1000 ms before stimulus onset until 2500 ms after stimulus onset were extracted from the data. Segments containing artifacts were automatically rejected if the difference between the minimum and maximum voltage exceeded 300 μV within the −500–2000 ms interval around stimulus onset in any channel of the subset (see 2.4 EEG recordings) or was less than .5 μV activity within a 100 ms interval in any channel of the subset. Bad channels (i.e., channels in which artifacts occurred in over 50% of segments) were deleted from the dataset. Participants' data was included in the analyses when at least 5 artifact-free trials (equal to 10 s) per condition were available (similar criteria have been used in studies of adults, see e.g. Harmon-Jones and Sigelman, 2001). On average 14 trials per condition were included (positive: M = 14 [range 5–20]; negative: M = 14 [range 6–20]; neutral: M = 14 [range 5–20]). A continuous wavelet transform (Morlet complex wavelet, 10 linear frequency steps from 2 to 20 Hz, morlet parameter c = 5, unit energy normalization) was used to calculate spectral power (μV2) within 10 frequency bands. We extracted the band with a central frequency of 8 Hz (bandwidth: 6.4–9.6 Hz) as a measure of alpha power (6–10 Hz in young children (Marshall et al., 2002)) for each trial and electrode. Average alpha power values within the 0–2000 ms interval were exported and natural log transformations were computed to normalize the data distributions. Frontal alpha asymmetry was computed by subtracting alpha activity over left frontal areas (electrode F3) from alpha activity over right frontal areas (electrode F4).

Data analysis

The behavioral data (mean pressing time per condition) and EEG data (frontal asymmetry) were checked for normality and outliers per sample. Pressing time showed one outlying value in the negative social judgment condition in test sample 1 (Z-value<−3.29) which was winsorized (Tabachnick and Fidell, 2006).

We used the MEMORE macro for SPSS (Montoya and Hayes, 2017) to examine whether frontal asymmetry during the SNAT-EC mediated the effect of condition (negative versus positive social judgments) on aggression (mean pressing time). Because the MEMORE macro allows for the inclusion of only two conditions in the within-subject mediation model, we decided to present results regarding the most important, likely largest, contrast of negative versus positive social judgments in the Results section and results regarding the other contrasts in the supplementary material. The MEMORE macro performs a series of regression analyses to estimate and test the effects of the independent variable, condition (negative vs. positive social judgments), on the mediator, frontal asymmetry (path a in Fig. 2) and on the dependent variable, pressing time (path c in Fig. 2). Also, the effect of the mediator on the dependent variable (path b) is tested. Finally, the overall mediation effect is tested by evaluating the significance of the indirect effect of the independent variable on the dependent variable through the mediator (path a * path b) using bootstrap analysis. The direct effect of the dependent variable on the independent variable that does not operate through the mediator is also computed (path c' in Fig. 2). Due to the nature of the regression models used the average value of the mediator across conditions (i.e., average frontal asymmetry across positive and negative social judgments) is automatically included as a moderator in the model (see Montoya and Hayes, 2017 for a detailed explanation). Alpha was set to .05, and the significance of the indirect effect was tested using the percentile bootstrap method with 10,000 iterations.

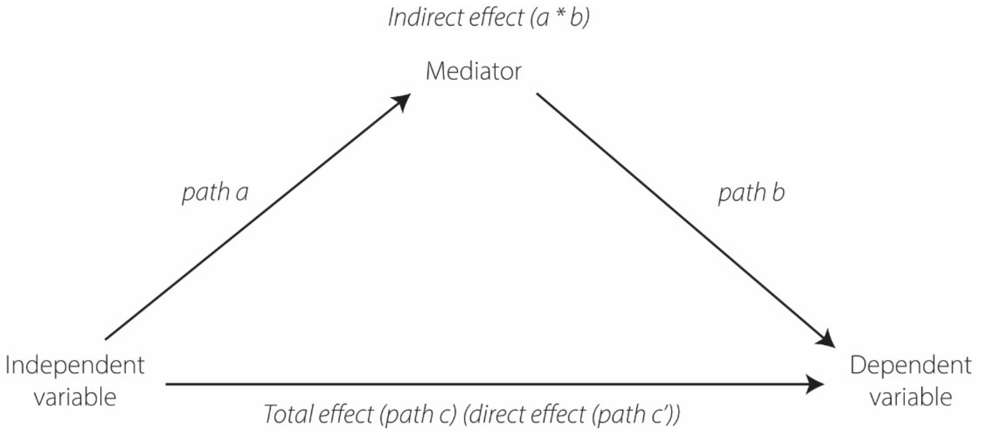

Figure 2. Within-subjects mediation model.

Finally, the results of the three samples were combined in a meta-analysis. Combined effect sizes were computed with the comprehensive meta-analysis (CMA) program using a random-effect model (Borenstein et al., 2009). We included t-values (with degrees of freedom) and standard errors in the meta-analysis to calculate Pearson correlations. To compute the effects of the mediation model the Pearson correlations were first transformed to Fisher z values and after meta-analytic combination back transformed to Pearson r's.

Results

Within-subjects mediation model

Results of the within-subject mediation models for all three samples are shown in Fig. 3. In the pilot sample a significant effect of condition (negative versus positive judgment) on aggression was found (total effect: $b = 794.02$, $SE = 242.73$, $p<.01$).[33] Negative judgments elicited on average 794 ms longer button presses than positive judgments, which corresponds to about two more balloons destroyed. This effect was not significantly mediated by frontal asymmetry in response to the social judgments (indirect effect: $b = 9.32$, bootstrapped $SE = 79.88$, 95% confidence interval (CI): $-136.91 - 208.35$), and the effect of condition on aggression remained significant when frontal asymmetry was taken into account (direct effect: $b = 784.70$, $SE = 254.18$, $p<.01$).

These effects were replicated in test sample 1: on average children pressed the button 802 ms longer (corresponding to two destroyed balloons) after a negative judgment compared to a positive judgment (total effect: $b = 802.28$, $SE = 213.71$, $p<.01$, direct effect: $b = 853.87$, $SE = 219.64$, $p<.01$). Again, this effect was not mediated by frontal asymmetry in response to the social judgments (indirect effect: $b = -51.60$, bootstrapped $SE = 77.51$, 95% CI: $-234.44 - 81.96$). Test sample 2 showed similar results: children pressed the button on average 828 ms longer (again corresponding to about two destroyed balloons) after negative judgments compared to positive judgments (total effect: $b = 828.78$, $SE = 184.85$, $p<.01$, direct effect: $b = 861.54$, $SE = 176.50$, $p<.01$), but this effect was not mediated by frontal asymmetry (indirect effect: $b = -32.77$, bootstrapped $SE = 79.73$, 95% CI: $-192.32 - 142.38$). Average frontal asymmetry across SNAT-EC conditions did not significantly moderate effects of condition in any of the three samples (pilot: $b = 689.82$, $SE = 1145.20$, $p = .55$, test 1: $b = 842.56$, $SE = 970.52$, $p = .39$ and test 2: $b = -1064.87$, $SE = 963.73$, $p = .28$).

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[3] The excluded sample (participants with behavioral data but no EEG data; pilot $N = 18$, test 1 $N = 17$, test 2 $N = 16$) showed similar effects and there were no significant differences between the included and excluded samples (pilot $F(37) = .11$, $p = .74$; test 1$F(42)= .07$, $p = .80$; test 2$F(44) = 2.88$, $p = .09$).

Meta-analysis

The results of the three samples were combined in a meta-analysis. The total effect of negative versus positive judgments on aggression showed a large combined effect size (r = .42, 95% CI: .29 – .54, p<.01). The indirect effect via frontal asymmetry was very small and not significant (r = –.03, 95%: –.13 –.07, p = .56). The direct effect of negative versus positive judgments on aggression controlled for effects on frontal asymmetry was similar to the total effect and significant (r = .34, 95% CI: .24 – .44, p<.01), see Table 2. All outcomes were homogenous (p>.05).

Table 2. Meta-analysis of the within-subjects mediation model effects on three samples

	Sample	r	95% CI	95% CI
Total effect	Pilot	.453**	.153	.676
	Test 1	.390**	.154	.585
	Test 2	.432**	.230	.598
	random effect	.422**	.290	.539
Path A	Pilot	.037	-.161	.231
	Test 1	.011	-.163	.184
	Test 2	-.038	-.201	.128
	random effect	-.001	-.104	.102
Path B	Pilot	.041	-.156	.236
	Test 1	-.091	-.261	.085
	Test 2	.182*	.014	.340
	random effect	.046	-.116	.206
Direct effect	Pilot	.299**	.477	.098
	Test 1	.328**	.484	.153
	Test 2	.383**	.526	.218
	random effect	.341**	.435	.240
Indirect effect	Pilot	.012	.208	-.185
	Test 1	-.059	.116	-.231
	Test 2	-.035	.131	-.199
	random effect	-.031	.072	-.133

* $p < .05$; ** $p < .01$

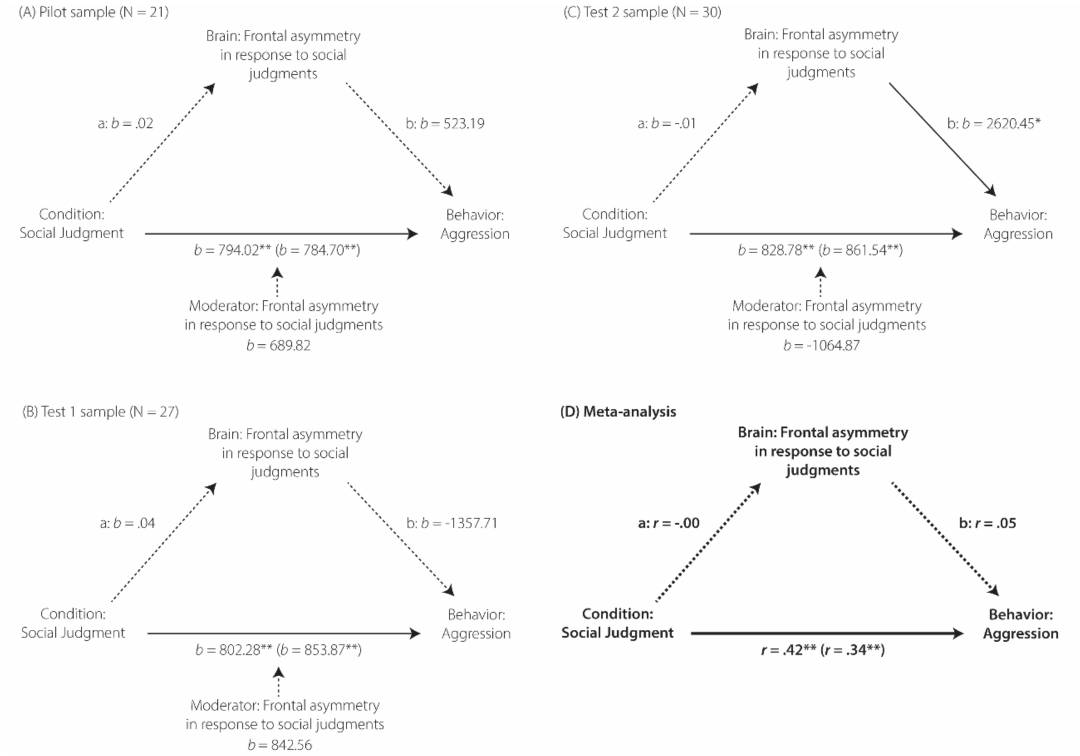

*Figure 3***.** Within-subjects mediation models shown separately for (A) pilot sample, (B) test sample 1 and (C) test sample 1. Combined results from the meta-analysis are shown in (D). A significant effect of social judgments (negative and positive) on aggressive behavior (mean pressing time) was found, shown with solid lines (** $p < .01$). This relation was not mediated by frontal asymmetry (solid line, * $p < .05$, dotted lines, $p > .05$). The indirect effect was not significant (pilot sample: $b = 9.32$, 95% CI: -136.91 - 208.35; test sample 1: $b = -51.60$, 95% CI: -234.44 - 81.96; test sample 2: $b = -32.77$, 95% CI: -192.32 - 142.38, meta-analysis: $r = -.03$, $p = .56$). Meta-analysis revealed a large combined effect size for the total and direct effect (solid line, ** $p < .01$).

Discussion

We investigated whether left frontal asymmetry mediates the relation between negative social judgments and aggressive behavior in young children. We included three samples (pilot, test 1 and test 2) to test the robustness of the results and combined our findings using meta-analysis. The results revealed a strong effect of social judgments on behavior: a negative social judgment led to more aggressive behavior than a positive social judgment. However, this effect was not mediated by frontal asymmetry. These results were replicated in all samples and a meta-analysis showed that the effect of social judgment on aggressive behavior is large.

A strong effect of social judgment on aggressive behavior conforms to our expectations and is in line with previous research showing a comparable effect of social judgment on aggressive behavior in adults (Achterberg et al., 2016) and older children (Achterberg et al., 2017; Overgaauw et al., submitted for publication; Dodge et al., 2003). The task design used in the current study was an adapted version of the SNAT used in the study by Achterberg et al. (2016, 2017) and Overgaauw et al. (submitted for publication) in which participants could respond to the judging peer with a loud noise blast. By replicating these behavioral results in young children, we have shown that the SNAT-EC is an age appropriate task to examine the behavioral response to social judgments in early childhood. Moreover, the meta-analysis for positive versus negative social judgments revealed a large combined effect size, providing evidence that negative social judgments indeed result in more aggressive behavior. Furthermore, the effect was replicated in two samples which together with the large meta-analytic results indicates that the effects found are robust. However, we do see smaller effect sizes for the effect of social judgments on aggressive behavior in early childhood (ω2 ranging from .12 to .15) compared to 7–10 year old children (ω2 ranging from .30 to .46; Achterberg et al., 2017) and adults (ω2 = .41; Achterberg et al., 2016). An important issue for further research is whether the increasing effect of social judgments on aggressive behavior as measured with the SNAT is related to the more profound emotional impact of rejection or with improving cognitive and/or motor skills over age.

Contrary to our expectations, left frontal asymmetry did not mediate the relation between negative social judgments and aggressive behavior. Our mediation hypothesis was based on studies showing a relation between greater relative left frontal activity and anger and aggression in adults (Harmon-Jones, 2004; Harmon-Jones and Sigelman, 2001; Verona et al., 2009). Results obtained with adults may not be directly generalizable to children both because of potential developmental issues and because of differences related to the behavioral and neural measures obtained (including e.g., data quality and quantity, and the selection of EEG frequency bands). We relied on evidence from adult samples, because studies relating frontal asymmetry to direct measures of aggressive behavior in children were lacking. Instead, aggressive behavior in children is often examined using parent and teacher reports. Indeed, only few studies have investigated relations between frontal asymmetry and caregiver-reported externalizing behavior (which includes, but extends beyond aggressive behavior) in young children. A recent meta-analysis showed no relation between left frontal asymmetry and externalizing behavior (effect size of d = .04, p = .79; (Peltola et al., 2014)). Although this, in combination with our own findings, suggests that left frontal asymmetry may not be related to aggressive behavior in early childhood, some caveats regarding the quantification of cortical activity in early childhood must be kept in mind. First, frontal asymmetry studies in children often do not report the minimum number of trials used in their analyses, neither for resting/trait-related frontal asymmetry nor state-related frontal asymmetry. Future research should investigate the reliability of frontal asymmetry in children in order to determine the minimum amount of EEG-data needed for reliable frontal asymmetry scores. Second, the frequency composition of the EEG is known to change over the course of development, but whether and how this affects frontal asymmetry is poorly understood (Saby and Marshall, 2012). Although research has directly related power in the 8–12 Hz EEG alpha band in adults to deactivation of cortical tissue (Cook et al., 1998; Laufs et al., 2003), no such evidence is, to the best of our knowledge, available for young children. Rather, estimates of the alpha frequency bandwidth in infants and young children are based on developmental changes in the peak frequency of the EEG (Marshall et al., 2002). Previous studies have varied in their choice of the alpha bandwidth (see Peltola et al., 2014), limiting the possibility to compare our results to previous findings. Studies examining the development of the EEG frequency composition, ‘alpha’ bandwidth, and frontal asymmetry in children are thus badly needed.

In addition, we chose to focus on frontal asymmetry because of its suggested link to aggressive feelings and behaviors (expressed in destroying balloons in the SNAT-EC), but primary emotional responses to rejection, preceding aggression, may also be of relevance. Some children might feel sad after receiving a negative social judgment whereas others might feel angry. Both emotions can lead to aggressive behavior (see e.g. Buckley et al., 2004), but they may impact differently on patterns of frontal asymmetry, as sadness, in contrast to anger, is a withdrawal-related emotion (Coan et al., 2001). Future studies should additionally measure participants’ (primary) emotional responses to positive, negative and neutral social judgments. However, it is important to note that the children in the current study were relatively young and might therefore experience problems in correctly indicating or nuance their emotional state (Chambers, and Johnston, 2002).

Future studies could also address some limitations of the current study. First, the external validity of laboratory measures is sometimes debated: it is questioned whether findings obtained using experimental tasks in laboratory settings generalize to real life situations. However, aggression measured in a laboratory setting was meta-analytically shown to be highly generalizable to real-world aggression (Anderson and Bushman, 1997). In addition, an observational study by Dodge et al. (2003) investigating social rejection and aggression showed similar findings to our own: social rejection by peers was related to an increase in aggressive behavior. We therefore feel that the conclusion that our experimental paradigm (SNAT-EC) is relevant for examining aggressive behavior in response to social judgments in early childhood is warranted. Second, the three samples were relatively small, mainly because about 50% of the participants in each sample provided no usable data. Such percentages of attrition are, however, rather common in EEG research with young children (Bell and Cuevas, 2012). It is quite challenging for children to sit still during EEG measurements (resulting in relatively high percentages of movement and ocular artefacts) and some children refuse to wear a cap or net at all. Although the sample sizes are relatively small, note that the results of the pilot sample were replicated in the two other samples, and that the meta-analysis showed a large effect size for the relation between social judgment and aggressive behavior, enhancing confidence in the validity and robustness of our findings. Furthermore, as the power to detect an indirect effect is as large as or (often) larger than the power to detect the main and direct effects, power and sample size are not of greater concern for mediation analysis (Kenny, and Judd, 2014). Next to that, we used a within-subjects design which has increased statistical power compared to a between-subjects design as it doesn’t include error variance due to stable individual differences (Kenny, and Judd, 2014). Nevertheless, adequate sample size remains an important consideration for future studies and we continue to search for ways to enhance children's willingness to comply with EEG measurements. Third, one could argue that, children may like to destroy balloons and that, as a consequence, we were not measuring aggressive behavior in response to social judgments. However, we controlled for individual differences in children's pleasure or interest in popping balloons by using a within-subjects design, in which we compared the mean pressing time after negative social judgments to the mean pressing time after positive social judgments on an individual level. Finally, we decided not to judge the children on personal characteristics but on a self-chosen cuddly animal for ethical reasons, which might have influenced the results. However, as stated above, the behavioral results were very robust. In addition, the children had been playing with the cuddly animal in the two weeks prior to the lab visit and they were clearly attached to their cuddly animal as evident from the stories the children told us, many children gave the cuddly animal a name and carried it along everywhere they went. Thus, we are confident that our paradigm successfully elicits experiences of (mild) rejection. For a measure of the children's attachment to the cuddly animal, future research may include questions asking for example how much time the child spent with the animal and whether it was the child's favorite toy.

Future studies should search for other neurocognitive mechanisms that may mediate the relation between social judgments and aggressive behavior. One might think of several event related potential (ERP) components as possible mediators, for example, components related to the processing of negative feedback, like the FRN (Feedback-Related Negativity) or components reflecting the allocation of attention like the P3 (Luck, 2014). A study in adults using the social judgment paradigm by Somerville and colleagues (2006) found an enhanced P3 only after expected acceptance (van der Veen et al., 2013). However, another study in adults did not find significant differences between positive and negative social judgments in FRN or P3 amplitudes (van der Molen et al., 2014). These authors did, however, find increases in midfrontal theta power, believed to index feedback processing, after unexpected rejection (van der Molen et al., 2016). In the current study we could not test the mediating role of ERPs, because the reliable measurement of ERP components requires larger numbers of artifact-free trials than were available from our participants (see also Huffmeijer et al., 2014). Theta power warrants study as a possible mediator. However, more research on the development of the theta frequency band is necessary (Saby and Marshall, 2012).

In conclusion, the current study showed that the SNAT-EC is an age appropriate task to reliably measure aggressive behavior in response to negative social judgments in young children. Frontal asymmetry during the task did not mediate the relation between social judgment and aggressive behavior in early childhood and other neurocognitive mechanisms should be examined to bridge the brain-behavior gap between social judgments and aggressive behavior.

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