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Neural and Affective Responses to Prolonged Eye Contact with One's Own Adolescent Child and Unfamiliar Others

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ABSTRACT

Eye contact is crucial for the formation and maintenance of social relationships, and plays a key role in facilitating a strong parent-child bond. However, the precise neural and affective mechanisms through which eye contact impacts on parent-child relationships remain elusive. We introduce a task to assess parents' neural and affective responses to prolonged direct and averted gaze coming from their own child, and an unfamiliar child and adult. While in the scanner, 79 parents (n = 44 mothers and n = 35 fathers) were presented with prolonged (16-38 s) videos of their own child, an unfamiliar child, an unfamiliar adult, and themselves (i.e., targets), facing the camera with a direct or an averted gaze. We measured BOLD-responses, tracked parents' eye movements during the videos, and asked them to report on their mood and feelings of connectedness with the targets after each video. Parents reported improved mood and increased feelings of connectedness after prolonged exposure to direct versus averted gaze and these effects were amplified for unfamiliar targets compared to their own child, due to high affect and connectedness ratings after videos of their own child. Neuroimaging results showed that the sight of one's own child was associated with increased activity in middle occipital gyrus, fusiform gyrus and inferior frontal gyrus relative to seeing an unfamiliar child or adult. While we found no robust evidence of specific neural correlates of eye contact (i.e., contrast direct > averted gaze), an exploratory parametric analysis showed that dorsomedial prefrontal cortex (dmPFC) activity increased linearly with duration of eye contact (collapsed across all "other" targets). Eye contact-related dmPFC activity correlated positively with increases in feelings of connectedness, suggesting that this region may drive feelings of connectedness during prolonged eye contact with others. These results underline the importance of prolonged eye contact for affiliative processes and provide first insights into its neural correlates. This may pave the way for new research in individuals or pairs in whom affiliative processes are disrupted.

1. Introduction

Humans are hard-wired to connect with others and an important non-verbal strategy to form and maintain strong social ties with others humans is by making eye contact (Emery, 2000; Hietanen, 2018; Kellerman et al., 1989). Receiving a direct gaze induces positive feelings and signals social inclusion, which fulfills our intrinsic need to belong, and to be literally *'seen'* (Hietanen et al., 2018; Hietanen et al., 2020; Kiilavuori et al., 2021; Kleinke, 1986). Eye contact constitutes one of the first acts of reciprocity between a parent and a child (Robson, 1967), and is thought to be an important facilitator for a strong parent-child bond and secure attachment. Moreover, positive affective responses of parents to eye contact with their own child are thought to reinforce sensitive caregiving behavior (Robson, 1967). To date, we know remarkably little about what exactly happens in the parental brain when parents make eye contact with their child. Nor do we know whether these responses are unique to the parent-child context or generalize to eye contact with unfamiliar others. A better understanding of the role of eye contact in social interaction might generate new insights for those having difficulties connecting with others via eye contact on a social and emotional level, both within and beyond the parent-child context, and pave the way for interventions. Therefore, we examined neural and affective processes in parents when they make prolonged eye contact with their own child. We contrast personalized videos of their own child against videos of an

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unfamiliar child or adult and employed a multimethod approach including self-reports of affect, functional magnetic resonance imaging (fMRI), and eye tracking.

It is known that people show specific (neural) response to faces of personally familiar compared to unfamiliar others (Petrowski et al., 2019; Ramon & Gobbini, 2018; Taylor et al., 2009), and such studies have often been conducted within the parent-child context (Abraham et al., 2018; Atzil et al., 2011; Barrett et al., 2012; Elmadih et al., 2016; Kuo et al., 2012; Lenzi et al., 2009; Wan et al., 2014). In response to the sight of their own child (versus unfamiliar children) parents typically show increased activation in neural networks supporting complex social functions that are important for parental caregiving, such as theory of mind, empathy, and interpersonal closeness/attachment (i.e., medial prefrontal cortex (MPFC), temporal parietal junction (TPJ), anterior insula, anterior cingulate cortex, amygdala, and inferior frontal gyrus (IFG) (Abraham et al., 2018; Atzil et al., 2011; Shimon-Raz et al., 2021). Moreover, these brain regions have been consistently linked to parental caregiving and attachment to the child and activations were independent of a child's age, representing one's attachment relationship throughout life from infancy to adulthood (Shimon-Raz et al., 2021; Ulmer-Yaniv et al., 2021).

In addition to neuroimaging studies on the processing of faces as a whole, there is a vast amount of research on neural responses to direct (versus averted) gaze of unfamiliar individuals. These studies have broadly distinguished two networks: A subcortical pathway (i.e., superior colliculi/periaqueductal grey, pulvinar nuclei and amygdala) for a 'quick and dirty' detection of gaze direction and a more reflective cortical pathway (i.e., fusiform gyrus, superior temporal sulcus, MPFC and orbitofrontal cortex) for the evaluation of eye contact, i.e. theory of mind and mentalizing (Hietanen, 2018; Senju & Johnson, 2009). However, these pathways are based on studies generally using stimuli with a short duration (< 2 seconds) and with a focus on the effect of gaze direction on facial recognition processes, while the neural correlates of prolonged eye contact are understudied. This is striking as the affiliative role of eye contact in interpersonal contact with others most likely comes into play as the duration of eye contact increases. For example, behavioral studies have shown that a prolonged presentation duration of dynamic face stimuli induces greater emotional engagement (Cowan et al., 2014; Regenbogen et al., 2012) and more favorable judgements from receiver to sender (Argyle et al., 1974; Brooks et al., 1986; Kuzmanovic et al., 2009; Montgomery et al., 1998). Prolonged exposure is also thought to more strongly engage higher-order cognitive processes related to the evaluation of eye contact, such as mentalizing in order to infer others' thoughts and feelings (Eskritt & Lee, 2007; Kuzmanovic et al., 2009). To date, only two studies focused on neural responses to prolonged eye contact. Kuzmanovic et al. (2009) examined the impact of varied gaze durations (i.e., 1, 2.5, and 4 s) on participants' neural responses to direct and averted gaze and found that increased duration of direct gaze resulted in differential neural responses in MPFC, including orbitofrontal and paracingulate regions. In addition, Cavallo et al. (2015) examined participants' neural responses to prolonged eye contact using stimuli of 15-30 s. They reported differential neural activation in IFG, anterior insula, pre-motor and supplementary motor area in response to direct versus averted gaze (i.e., gaze direction) of others, brain regions involved in the preparation of a communicative response, also referred to as a 'readiness potential' for the initiation of a social interaction (Cavallo et al., 2015; Gallagher, 2014; Pfeiffer et al., 2013; Saito et al., 2010). In addition, Cavallo et al. (2015) found the dorsomedial prefrontal cortex (dmPFC) to be specifically activated in case participants reciprocated the direct gaze of the target to establish a mutual gaze.

To capture neural correlates of positive affect and feelings of connectedness elicited by prolonged eye contact, we developed a new fMRI paradigm to examine parents' neural and affective responses to direct versus averted gaze stimuli with a prolonged presentation duration of 16-38 s. In this task, parents ($n = 79$, 44 mothers and 35 fathers) of adolescent children (aged between 12-18 years) made eye contact with their own child versus an unfamiliar child and adult. More specifically, we examined whether parents report a better mood and enhanced feelings of connectedness (affective responses) and show enhanced neural responses while making eye contact with others, and whether this is modulated by the person with whom they made eye contact in the videos (i.e., own child, an unfamiliar child or unfamiliar adult). In addition, we examined to what extent parents gazed towards the eye region of the targets during the direct gaze (versus averted gaze) conditions and whether these responses are modulated by the identity of the targets. As adolescence is a crucial period for social development and a good parent-child relationship is one of the most important factors supporting adolescents' wellbeing (Steinberg & Silk, 2002), it is of great importance to not only examine parental responses in parents of babies or young infants, but also during adolescence. In addition, adolescents start to become more autonomous in their relationship with their parents and eye contact might substitute physical contact between a parent and child that is more pronounced during infancy and may be less appreciated during adolescence (Montemayor, 1983; Montemayor, 1986; Steinberg & Silk, 2002).

All study measures, hypotheses, and analyses were preregistered at Open Science Framework prior to data analyses (https://osf.io/54nky/). Based on prior studies on parent-child bonding (Abraham et al., 2018; Atzil et al., 2011; Barrett et al., 2012; Elmadih et al., 2016; Kuo et al., 2012; Lenzi et al., 2009; Wan et al., 2014), we expected that parents report a better mood and enhanced feelings of connectedness after making eye contact with others (compared to an averted gaze). We also expected that differences in mood and feelings of connectedness between direct and averted gaze were most pronounced in response to videos of the own child versus an unfamiliar child or adult. At the neural level, we expected that parents generally show increased neural responses in the subcortical and cortical pathway of face processing in response to direct versus averted gaze. We hypothesized that parents would show enhanced responses in neural networks supporting social cognition, such as theory of mind (i.e., MPFC, TPJ) and salience processing (i.e., insula, ACC, amygdala) in response to videos of their own child versus an unfamiliar child or adult. Based on prior work (Leibenluft et al., 2004), we expected enhanced responses at the neural, but not at the affective level, to an unfamiliar child versus adult. Lastly, we explored an interaction between gaze direction (i.e., direct versus averted gaze) and target person (i.e., with whom parents made eye contact) to examine whether a direct gaze facilitates parents' responses to their own child versus others. We expected that parents would gaze more towards the eyes of targets during direct versus averted gaze videos. Given that no studies have examined whether gazing to the eyes of others is modulated by personal familiarity or interpersonal closeness (i.e., own child vs unfamiliar targets), we formulated no concrete hypotheses regarding this question.

2. Method

2.1. Participants

Data were collected in the context of the RE-PAIR study: *"Relations and Emotions in Parent-Adolescent Interaction Research"*. The RE-PAIR study uses a multi-method approach to examine the relation between parent-child interactions and adolescent depression by comparing families with an adolescent with a current diagnosis of Major Depressive Disorder (MDD) or dysthymia to families with an adolescent without psychopathology. Families were included in the study in case the adolescent and at least one of the parents/caregivers were willing to participate in the study and had a good command of the Dutch language. Families were explicitly asked to participate with both parents/caregivers, if possible, although this was no requirement for inclusion. Adolescents were required to be aged between 11 and 17 years at study inclusion and to live with at least one of their parents/caregivers. Families with

Table 1
Demographic characteristics.

Mean (SD) / n (%)	All parents (*n* = 79)	Mothers (*n* = 44)	Fathers (*n* = 35)	Mothers vs. fathers[1] t / χ^2	*p*
Age parent, years	49.87 (4.62)	48.03 (3.89)	52.19 (4.47)	4.43	<.001
Age adolescent, years	16.44 (4.23)	17.19 (5.42)	15.51 (1.51)	0.77	.082
Gender adolescent					
Boys, n (%)	25 (31.6)	13 (29.5)	12 (34.3)	0.04	.842
Girls, n (%)	54 (68.4)	31 (70.5)	23 (65.7)	1.19	.276
Adolescent depression severity[2]	8.11 (7.04)	7.07 (6.65)	9.43 (7.40)	1.49	.140
Education of parents					
Vocational training, n (%)	18 (22.8)	11 (25.0)	7 (20.0)	0.89	.346
Higher education, n (%)	61 (77.2)	33 (75.0)	28 (80.0)	0.41	.522

Note. SD, Standard deviation.

[1] *p*-values were obtained using independent samples t-tests or Chi-square comparisons between mothers and fathers.

[2] Assessed with the Patient Health Questionnaire (PHQ-9; Kroenke et al. (2001)) prior to the first visit in the lab.

an adolescent without psychopathology were included in the study in case they were not diagnosed with a (neuro)psychiatric disorder in the two years leading up to the study and had no lifetime diagnosis of MDD or dysthymia. Families with an adolescent with MDD/dysthymia were included in the study in case the adolescent met criteria for one of these current primary diagnoses, verified with the Kiddie-Schedule for Affective Disorders and Schizophrenia Present and Lifetime version (K-SADS; Kaufman et al. (1996)). Families could not participate if the adolescent met criteria for a primary diagnosis of a current (neuro)psychiatric disorder other than MDD or dysthymia, or a comorbid psychosis, substance use disorder or mental retardation. Additionally, exclusion criteria for the functional magnetic resonance imaging (fMRI) part of the study were incompatibilities with MRI scanning (e.g., metal implants, pregnancy).

The current study focused on fMRI data collected during the scan session both from parents of adolescents with and without psychopathology in this larger study. Eighty-five parents participated in this study. Six parents were excluded from data analyses due to brain abnormalities ($n = 1$), ending the scan session due to symptoms of sleep apnea ($n = 1$), incomplete datasets ($n = 3$), and a posteriori clinical diagnosis of the adolescent other than a primary diagnosis of MDD or dysthymia ($n = 1$). This resulted in a final sample of 79 parents of adolescents, including 44 mothers ($M_{age} = 48.03$ years, $SD_{age} = 3.89$) and 35 fathers ($M_{age} = 52.19$ years, $SD_{age} = 4.47$). See Table 1 for details on sample demographics.

The study was approved by the medical ethical committee of the Leiden University Medical Centre (LUMC) (P17.241) and was performed in accordance with the declaration of Helsinki and the Dutch Medical Research Involving Human Subjects Act (WMO).

2.2. Procedure

Families with an adolescent without psychopathology were recruited via public advertisements and (online) social media, including Facebook and advertisement in the monthly magazine of the Royal Dutch Touring Club (ANWB). Families with an adolescent with MDD/dysthymia were recruited via mental health facilities. Parents and adolescents were briefed about the study and underwent a comprehensive telephone screening during which family circumstances and informed consent were discussed and adolescents were pre-screened for (a history of) psychiatric disorders. Families were invited for two appointments: An assessment day in the lab and an MRI session on a separate day. Prior to the first appointment parents were asked to fill out an online questionnaire battery including demographics and clinical and cognitive measures. During the first appointment, families performed parent-adolescent interaction tasks and filled out additional questionnaires, and parents were screened on current psychopathology with the Mini International Neuropsychiatric Interview (see Supplement 1). During the second appointment, parents underwent an MRI scan at the LUMC in Leiden, the Netherlands. Prior to the scan, parents filled out a set of questionnaires, received instructions about the MRI tasks, and performed some practice trials. Parents performed three tasks in the MRI scanner: The eye contact task as described below, a parental empathy task (Wever et al., 2021), and the vicarious social feedback task (van Houtum et al., 2021). Upon completion of the MRI scans, parents were fully debriefed about the goals of the study and received a monetary compensation and travel allowance. Parents provided written informed consent for each individual testing day. The median of days between the first and second appointment was 37 and ranged between 7 and 265 days.

2.3. Measures and materials

2.3.1. Eye contact task

To characterize neural and affective responses to prolonged eye contact, we developed a new fMRI paradigm. During the task, parents were shown pre-recorded video stimuli of four targets, including their own child, an unfamiliar child, an unfamiliar adult, and themselves; all facing the camera. Each video contained a single target who looked straight into the camera (direct gaze) or averted their gaze to the left side of the camera (averted gaze), resulting in eight distinct videos: Gaze direction (2 levels: direct versus averted gaze) × target (4 levels: own child, unfamiliar child, unfamiliar adult, self). We measured parents' eye movements during the task using an MRI compatible eye-tracking set-up.

See Fig. 1 for an overview of the task. While in the scanner, parents were instructed to make eye contact with the persons in the videos. Each trial started with a fixation cross (duration: 2-5 s), after which parents were presented with a video of one of the targets (i.e., own child, unfamiliar child, unfamiliar adult, self) in one of the gaze directions (i.e., direct gaze or averted gaze) for 16-38 s. The gender of the unfamiliar adult was matched to parents' own gender and the gender of the unfamiliar child was matched to the parents' child with whom they participated in the study. After watching videos including parents' own child, an unfamiliar child, and an unfamiliar adult, parents were asked to answer three questions; (1) "How connected do you feel with this person at this moment?", (2) "How do you feel about this person at this moment?", and (3) "How do you feel at this moment?". After the videos of the self, parents only reported on their mood. Parents could rate their affect on a 7-point Likert scale ranging from 1 (*not at all/very negative*) to 7 (*very much/very positive*) and they were instructed to answer and confirm the question within 8 s. The questions were self-paced and they could press any button to display a box around the middle option and then press the button corresponding to their right index (to go left) and right middle finger (to go right) to move the box to their preferred answer. They could confirm their answer by pressing the button corresponding to their left index finger. Prior to performing the task, outside the scanner, parents

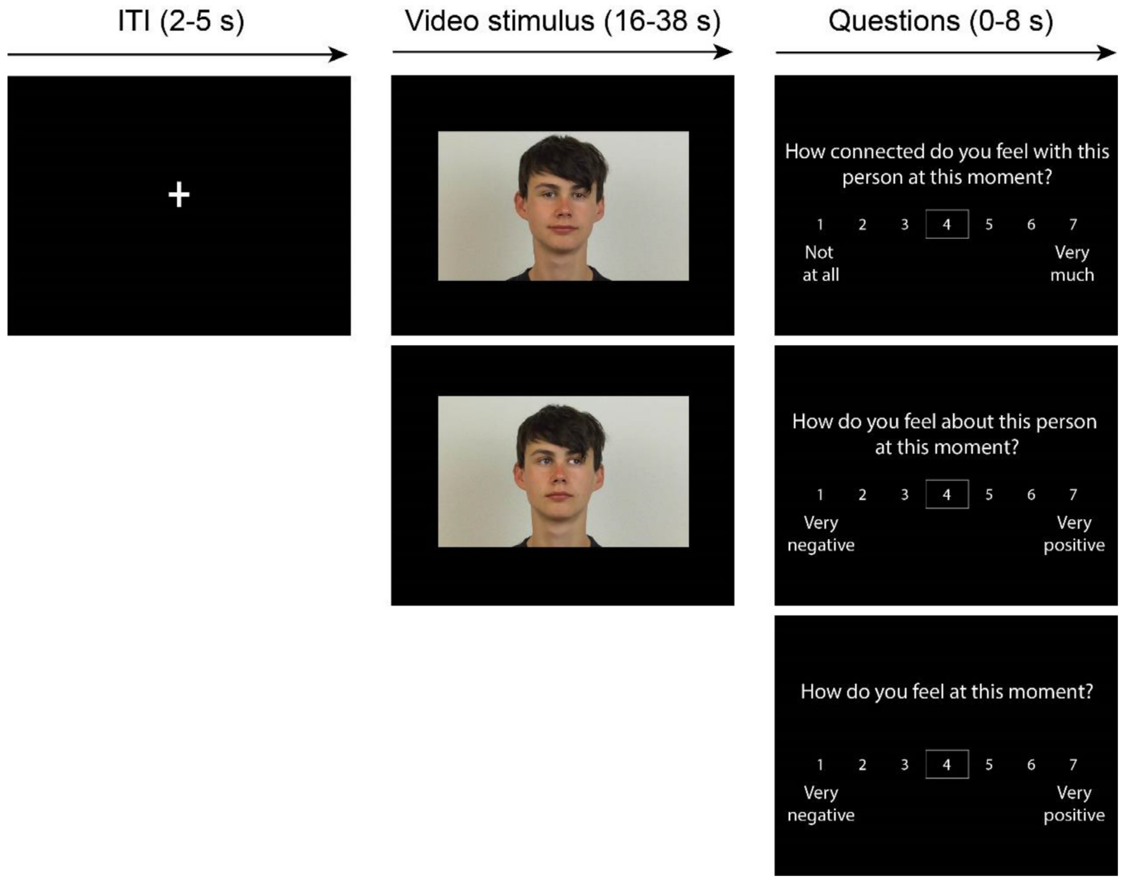

Fig. 1. Displays and timings of video stimuli of one's adolescent child engaging in direct gaze and averted gaze in the eye contact task. Videos of parents' own child were contrasted against videos of an unfamiliar child matching the gender of the parents' own child, a video of an unfamiliar adult of the same gender as the parent and a video of the self. When parents were presented with a video of the own child and an unfamiliar child or adult, they were asked to answer all three questions, and when they were presented with a video of themselves they were only asked to answer the last question (i.e., "How do you feel at this moment?").

rated their mood, how they felt about the person, and how connected they felt with the person in the videos in response to static pictures of each target with a direct gaze. We included these baseline measures to ascertain whether increases in affect in response to prolonged direct gaze in the task could be attributed to making prolonged eye contact relative to baseline.

For the preparation of the video fragments, we recorded videos of the parents and their adolescent children during the lab visit. The videos had to have a minimal duration of 45 s and were recorded in front of a white wall. Parents and adolescents were wearing a black t-shirt during the recordings to avoid distraction due to their clothing. We asked parents and adolescents to look in the camera with a friendly, but neutral, facial expression and to imagine looking into the eyes of their child/parent. They were also instructed not to stare, but to gaze as natural as possible and blinking was allowed. The target persons of the unfamiliar child and unfamiliar adult conditions of both genders were approached in the context of stimuli development for the current task and were selected based on age (between 45-55 years for the unfamiliar adults and between 11-17 years for the unfamiliar child) and gender. Videos were recorded under similar circumstances as videos of parents and children who participated in the study and written informed consent was taken to confirm the approval of the targets to use their videos in the current study. All videos were presented twice in two separate runs ($2 \times 8 = 16$ trials in total). For the first run, all targets were presented in a random order. For each target, parents were presented with two successive videos of the same target, but with gaze direction randomized (i.e., either starting with direct gaze or averted gaze, followed by the other direction). For the second run, the order of targets was randomized again, but the order of the presentation of the gaze direction was counterbalanced to the first run. The durations of the videos were based on a randomly chosen interval between 16-38 s from prerecorded videos of 45 s. The first and last 3 s of each prerecorded video were discarded due to reduced recording quality. Stimuli from each condition were presented for a total duration of 54 s across two repeats, meaning that duration of a stimulus in a specific condition in run 2 was 54 s minus stimulus duration in run 1 with a minimum of 16 s (range: 16-38 s). Stimulus presentation and simultaneous eye movement recordings were conducted using E-Prime 2.0 software (PsychologySoftware Tools, Pittsburgh, PA, United States) and the screen resolution was 1024×768 pixels. The videos were presented on the screen in 960×540 pixels. The task took about $\pm$ 11 min in total.

2.3.2. *Eye tracking*

Eye movements during the eye contact task were recorded with a tower mounted monocular EyeLink 1000 MRI-compatible remote eye tracker with 1000 Hz sampling rate (SR Research Ltd., Mississauga, Ontario, Canada). The eye tracker was placed inside the scanner bore and detected the pupil and corneal reflection of the right eye via a mirror attached to the head coil. The eye tracker was calibrated and validated using a nine-point calibration grid from EyeLink's own calibration protocol (see below for details).

2.3.3. *Data acquisition*

MRI images were acquired at the LUMC using a Philips 3.0T Achieva MRI scanner equipped with a SENSE-32 channel head coil. For the eye contact task, T2*-weighted echo planar imaging (EPI) was used with the following parameters: TR = 2200 ms, TE = 30 ms, flip angle = 80°, FOV 220 × 220 × 114.7 mm, matrix size = 80 × 80, voxel size = 2.75 mm^3, slice gap = 0.275 mm, 38 transverse slices in descending order. As subjective response ratings were self-paced, number of volumes varied between participants (run 1: M = 152.6, SD = 12.2, range = 128 – 189; run 2: M = 149.1, SD = 12.3, range = 123 – 184). A structural 3D T1 scan was acquired with the following parameters: TR = 7.9 ms, TE = 3.5 ms, TI = 820 ms, flip angle: 8°, voxel size = 1 mm^3, 155 transverse slices FOV 195.8 × 250 × 170.5 mm, matrix size = 228 × 177, duration: 4:11 min. The first five volumes were discarded to allow for equilibration of T1 saturation effects. A b0 field map was acquired with the following parameters: TR = 200 ms, TE = 3.2, matrix size = 80 × 80, with 38 slices, voxel size = 2.75 mm^3. The task was programmed and presented electronically using E-prime 2.0 (Tools Psychology Software, 2012) and participants could see the task through a mirror attached to the head coil. Foam inserts were used to restrict head motion if necessary.

2.4. Data preprocessing and analyses

2.4.1. Affective responses

Self-report affective responses were analyzed in R (R Core Team (2013), version 3.6.1), with the following packages: lme4 for mixed model analysis, psych for descriptive statistics, and ggplot2 for creating figures (Bates et al., 2012; Revelle, 2012; Wickham et al., 2016). Questions that were not answered by the participants within a set time of 8 s were reported as missing values and excluded from the affective response analyses, but not from neuroimaging analyses, which resulted in 18 missing affective responses out of 3160 responses in total (0.6%).

To assess both the impact of eye contact (direct versus averted gaze) and how this may vary as a function of the target identity in the video, we used a generalized linear mixed regression model with gaze direction (2 levels: Direct gaze, averted gaze) and target (4 levels: Own child, unfamiliar child, unfamiliar adult, self) as predictors of parents' self-reported affective responses. We ran three separate generalized linear mixed regression models, one for each subjective rating: Feelings of connectedness, feelings about the targets, and mood of parents. We tested for main effects of gaze direction and target, and their interaction.

2.4.2. Eye tracking data analyses

We used a customized MATLAB (MathWorks, Inc., Natick, MA, version 9.5) script to preprocess raw eye tracking data into measures of eye gaze per parent per video clip. Raw gaze data of parents' right eye was used to calculate information on gaze position and duration. Furthermore, validity of gaze data was calculated as the percentage of successfully recorded eye tracking data per video clip as an estimate of data quality. Individual trials of which the validity was below 70% were excluded from further analysis, which is within the common range (Bojko, 2013). Visual inspection of the gaze data was performed to detect for aberrations in data quality. Gaze data of 16 participants could not be collected due to technical problems with the eye tracker in the scanner and gaze data of another 15 participants could not be collected due to an unsuccessful calibration procedure prior to the scan session, resulting in a final sample of gaze data of 48 participants. Reasons for failure of the calibration procedure were difficulty tracking the eyes when participants wore MR-compatible glasses (in case they could not perform the task without glasses) or when participants had light-colored eyes. In addition, 22 trials of five participants were excluded (min. 1 and max. 10 trials per person) due to missing gaze data for >30% of the duration of the trial. This resulted in gaze data of 746 trials in total (out of 768; 2.9% missing data) of 48 participants (out 79 participants for the fMRI study).

Areas of interest (AOI) in the stimuli were created around the left and right eye and the overall face area for all presented videos using MATLABs cascade object detector (Viola & Jones, 2001). This MATLAB toolbox used an established algorithm for face and facial feature detection. More specifically, for each frame of each video, this algorithm outputted rectangular AOIs encompassing the left eye, right eye, and overall face area. The primary eye gaze measure used was percentage of dwell time within the AOIs (i.e., left eye, right eye, overall face area) per video stimulus, as part of the total duration of the video (16-38 s), in which dwell time is defined as the total amount of time spent looking within an AOI and includes all types of eye movements (such as fixations and saccades). The gaze data within the right and left eye AOIs were combined into a single AOI of the eye region for further analyses. To examine whether the amount of eye contact was moderated by gaze direction (2 levels: Direct versus averted gaze) and target identity (4 levels: Own child, unfamiliar child, unfamiliar adult, self), we used a generalized linear mixed regression model in R with gaze direction and target as predictors of the percentage of dwell time towards the eye region of the targets. Furthermore, we examined whether parents who looked more at the eyes of targets reported a higher mood and enhanced feelings of connectedness. To do this, we used a similar generalized linear mixed regression model and included the percentage of dwell time towards the eye region, gaze direction, and target as predictors of self-reported affect.

We controlled for gender of the parents and current MDD/dysthymia diagnosis in the child of the parent in all analyses including affective and gaze responses of parents. In two cases, two parents of the same adolescent participated in the task. To control for potential dependencies in the data we added a covariate to the model indicating whether parents were part of the same family. Significance was set at $p < .05$ (two-tailed) and Cohen's d effect sizes were calculated for significant effects.

2.4.3. Neuroimaging analyses

MRI data were preprocessed and analyzed using SPM12 (Wellcome Trust Centre for Neuroimaging, University College London). Functional MR images were slice-time corrected, corrected for field-strength inhomogeneity's using b0 field maps, unwarped and realigned, co-registered to subject-specific structural images, normalized to MNI space using the DARTEL toolbox (Ashburner, 2007), and smoothed using an 8-mm full width half maximum isotropic Gaussian kernel. Raw and preprocessed data were checked for quality, registration, and movement. Head movement did not exceed 1 voxel (i.e., 3 mm) for any of the participants (M = 0.09 mm, SD = 0.05 mm, range: 0.002 – 2.759 mm). Furthermore, we corrected for serial autocorrelations using a first order autoregressive model (AR(1)). We removed low-frequency signals using a high-pass filter (cutoff = 128 s) and included nuisance covariates to remove effects of run.

To examine neural responses of parents to direct and averted gaze, identity of the person they made eye contact with (i.e., own child, unfamiliar child, unfamiliar adult and the self), and their interaction, we constructed a generalized linear model with eight regressors indicating cue onset for each condition separately and one regressor for onsets of subjective ratings. Cue onset regressors were defined from the onset of the video stimulus and modeled for the duration of this period (variable between 16-38 s). The subjective rating regressor was defined from the onset of each question and modeled for the duration the question was displayed on the screen, including 1000 ms during which a "Too late!" screen was shown in case participants did not answer within the set time period of 8000 ms (self-paced; mean duration = 3311 ms; SD = 1316 ms; range = 1029-9002 ms). We included 6 motion parameters (based on the realignment parameters) to correct for head motion. First, eight first-level SPM T-contrasts were specified for each condition (i.e., own child – direct gaze, own child – averted gaze, unfamiliar child – direct gaze, unfamiliar child – averted gaze, unfamiliar adult – direct gaze, unfamiliar adult – averted gaze, self – direct gaze, self – averted gaze). Second, these T-contrast images were entered in a 2 × 4 full factorial ANOVA design with two within-subject factors: Gaze direction (2 levels: Direct versus averted gaze) and target (4 levels: Own child, unfamiliar child, unfamiliar adult, self). Whole-brain SPM F-maps were computed

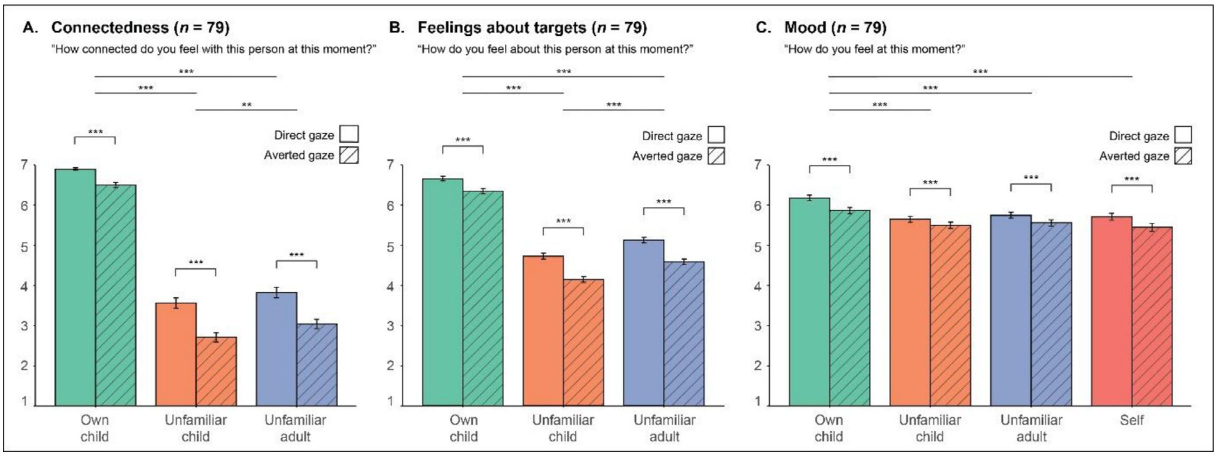

Fig. 2. Mean levels of self-reported feelings of connectedness, feelings about the targets, and parents' mood after the videos of all targets (i.e., own child, unfamiliar child, unfamiliar adult, self) in both gaze directions (i.e., direct and averted gaze). Parents reported enhanced feelings of connectedness (A), positive feelings towards another person (B), and mood (C) after prolonged direct gaze versus averted gaze. Parents felt more positive and connected after videos of their child versus others. Eye contact (Δdirect – averted gaze) induced greater effects on feelings of connectedness and feelings about others after videos of unfamiliar others compared to their own child. Error bars represent standard error of the mean. Significant *p*-values <.05 were indicated by *, *p* <.01 by **, and *p* <.001 by ***.

to assess main effects of target and gaze direction, and their interaction, followed up by post-hoc analyses between all conditions.

All whole-brain results were corrected for multiple comparisons with Family-Wise Error (FWE) cluster correction at $p < 0.05$ (with a cluster-forming threshold of $p < 0.001$). We performed control analyses to check for a potential impact of gender, handedness, current psychopathology and psychotropic medication status of parents, and current MDD/dysthymia diagnosis in the child on neural responses associated with making eye contact with different targets (Supplement 1).

3. Results

3.1. Affective responses

To assess the impact of eye contact (direct versus averted gaze) and how this may vary as a function of the targets in the videos, we performed a generalized linear mixed regression model with gaze direction (2 levels: Direct versus averted gaze) and target (4 levels: Own child, unfamiliar child, unfamiliar adult, self) on parents' affect ratings after the videos. Our analyses revealed that prolonged direct gaze generally resulted in stronger feelings of connectedness ($B = 0.39$, SE = 0.12, t(854) = 3.29, $p = .001$, $d = 0.65$), more positive feelings about the targets ($B = 0.32$, SE = 0.08, t(859) = 3.99, $p < .001$, $d = 0.68$) and a better mood ($B = 0.23$, SE = 0.03, t(1178) = 7.11, $p < .001$, $d = 0.40$) compared to averted gaze (see Fig. 2).

In addition, we found that parents' feelings of connectedness ($\chi^2(2) = 2238.0$, $p < .001$), how they felt about the targets ($\chi^2(2) = 1501.1$, $p < .001$), and their mood after the videos ($\chi^2(3) = 133.2$, $p < .001$) were strongly dependent on the target person (Fig. 2). Post-hoc pairwise (Bonferroni corrected) comparisons indicated higher levels of connectedness of parents with their own child versus an unfamiliar child ($p < .001$, $d = 3.41$) or an unfamiliar adult ($p < .001$, $d = 3.13$). Parents reported higher levels of connectedness with an unfamiliar adult versus an unfamiliar child ($p = .002$, $d = 0.27$). In addition, they reported more positive feelings about their own child versus an unfamiliar child ($p < .001$, $d = 2.92$) and unfamiliar adult ($p < .001$, $d = 2.33$), and more positive feelings about an unfamiliar adult versus an unfamiliar child ($p < .001$, $d = 0.60$). Lastly, parents reported a better mood after videos of their own child versus an unfamiliar child ($p < .001$, $d = 0.79$), unfamiliar adult ($p < .001$, $d = 0.64$), and self ($p < .001$, $d = 0.79$). Reported mood of parents did not significantly differ after videos of an unfamiliar child, an unfamiliar adult or the self (all p-values > .338).

There was a significant interaction between gaze direction and target on parents' feelings of connectedness ($\chi^2(2) = 8.86$, $p = .012$) and feelings about the targets ($\chi^2(2) = 6.35$, $p = .042$), showing that the difference in affect between the direct and averted gaze condition (Δdirect minus averted gaze) was smaller after the own child videos compared to the unfamiliar child and adult videos (Fig. 2). There was no significant interaction between gaze direction and target for self-reported mood.

To assess the impact of prolonged eye contact on parents' feelings about the targets and their mood, we compared parents' ratings of the static pictures of the targets prior to the scan session with their ratings after the direct gaze videos of each target in the first and second block of the task. These analyses revealed that prolonged eye contact enhanced parents' feelings about the targets and their feelings of connectedness, but it did not enhance parents' mood (see Supplement 2 for more details).

3.2. Gaze responses

To examine to what extent parents gazed towards the eye region of the targets during direct versus averted gaze videos and whether these responses are moderated by the identity of the targets, we performed a 2 × 4 generalized linear mixed regression analysis in participants of whom gaze data was successfully collected (48 out of 79 participants; 61% of the sample). We found a main effect of gaze direction, showing that parents overall gazed significantly more to the eye region of targets during direct versus averted gaze videos ($B = 2.46$, SE = 0.95, t(694) = 2.58, $p = .010$, $d = 0.19$) (Fig. 3-A and 3-B). Furthermore, we found a main effect of target ($\chi^2(3) = 36.71$, $p < .001$). Post-hoc pairwise (Bonferroni corrected) comparisons indicated a higher percentage of dwell time to the eye region of the unfamiliar adult, irrespective of gaze direction, compared to their own child ($p < .001$, $d = 0.61$), an unfamiliar child ($p < .001$, $d = 0.43$), or themselves ($p = .001$, $d = 0.38$), see Fig. 3-B. Parents did not significantly differ in the amount of gaze towards the eye region of their own child, an unfamiliar child, or to their own eye region (all p-values > .161). There was no significant interaction between gaze direction and target on the amount of gaze towards the eye region of targets ($p = .346$), showing that the difference in gaze towards the eye region between direct and averted gaze videos did not depend on the target in the video. Interestingly, parents' percentage of dwell time with respect to the overall face area did not differ between

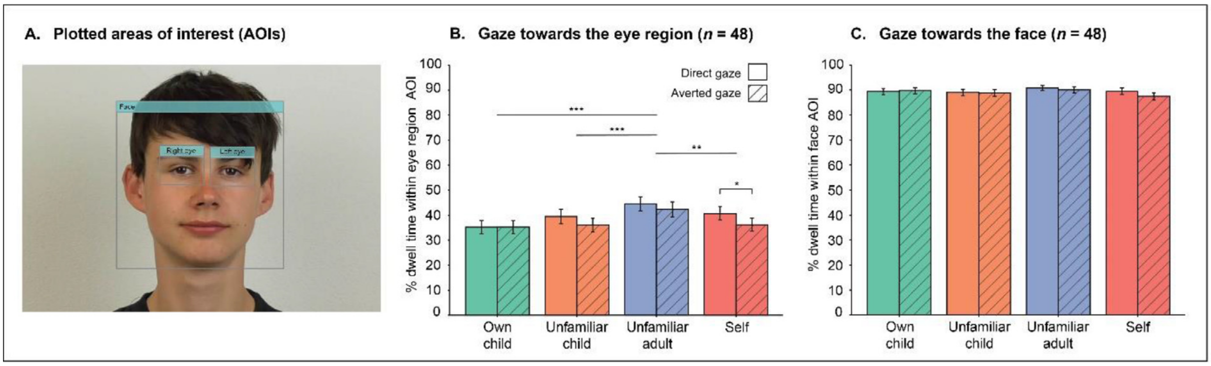

Fig. 3. Average levels of gaze of parents toward the eye region and the overall face area of targets (i.e., own child, unfamiliar child, unfamiliar adult, self) during videos with direct and averted gaze. Gaze was operationalized as the percentage of dwell time towards the eye region relative to the total video duration per video. The right and left eye AOIs were combined into a single AOI of the eye region (A). Overall, parents gazed significantly more towards the eye region of others during prolonged direct gaze versus averted gaze, and parents gazed significantly more towards the eye region of an unfamiliar adult compared to the other targets. There was no significant interaction between gaze direction and target on the amount of gaze towards the eye region of targets ($p = .346$) (B). Parents' percentage of dwell time with respect to the overall face area did not differ between the different targets (C). Error bars represent standard error of the mean. Significant p-values <.05 were indicated by *, p <.01 by **, and p <.001 by ***.

the different targets (Fig. 3-C), indicating that parents did not gaze more towards the unfamiliar adult versus the other targets in general and that the effect is specifically targeted to the eye region.

Lastly, we examined whether parents who made more eye contact reported increased feelings of connectedness to direct (minus averted) gaze videos with the targets. We correlated the difference score in the percentage of dwell time towards the eye region during direct minus averted gaze videos with the difference score in self-report ratings of connectedness after direct minus averted gaze videos for each target separately. However, parents who made more eye contact did not significantly report to feel more connected, for any of the targets (all p-values > .480).

In addition to our preregistered analyses, we conducted several additional analyses to examine the robustness of our gaze findings and visualized the gaze data over time. Instead of time spent looking towards the eye region of targets relative to total viewing time, we calculated the ratio between time spent looking towards the eye region of targets relative to time spent looking toward the face (excluding gazes outside of the face). All findings remained significant when analyzing this alternative measure of time spent looking at the eye region (see Supplement 3), supporting the robustness of the findings. In addition, we visualized average dwell time looking at the eye region of targets as videos progressed (i.e., binned average dwell time for each second of the video) to ascertain that parents continued to make eye contact with targets throughout the video presentations or directed their attention elsewhere after a certain amount of time. This revealed that parents gazed towards the eye region for a relatively stable duration over time, indicating that they closely followed the instruction to keep gazing towards the eye region of the targets throughout the trial (see Supplement 4). Lastly, we plotted the average dwell time duration per second over the course of the videos (16-38 s) per target to visualize whether the time parents spent looking at the eye region of targets differed depended on the target with whom they were making eye contact in the videos, but this did not result in observable differences between the targets (see Supplement 5).

3.3. Neural responses

To examine neural responses to direct versus averted gaze and whether these responses are modulated by the identity of the target in the video, we performed a whole-brain full factorial 2 (gaze direction) × 4 (targets) ANOVA on parents' BOLD-responses. This analysis yielded no significant main effect of gaze direction or a significant interaction effect between target and gaze direction. Together, these results did not reveal evidence for neural correlates of prolonged eye contact or for a hypothesis that different brain regions may be differentially sensitive to making prolonged eye contact with a specific target person. However, the analysis revealed a main effect of target in several brain regions, including right fusiform gyrus, left middle/inferior occipital gyrus, the triangular- and opercular part of right inferior frontal gyrus (IFG), TPJ, left IFG, left precentral gyrus, and the medial part of the right superior frontal gyrus (SFG)/dmPFC (Fig. 4-A, Supplement 6). Post-hoc (Bonferroni corrected) pairwise comparisons indicated that parents exhibited significantly decreased deactivation in BOLD-response in left middle/inferior occipital gyrus (p <.001), triangular- and opercular part of right IFG (two clusters, both p <.001), and right fusiform gyrus ($p = .013$) towards their own child versus an unfamiliar child. For their own child versus an unfamiliar adult, parents exhibited significantly decreased deactivation in BOLD-response in left middle/inferior occipital gyrus ($p = .003$) and right IFG ($p = .010$). Results indicated no significant differences in BOLD-responses to an unfamiliar child versus an unfamiliar adult. In addition, we found several brain regions that were significantly less activated when parents look at the videos of themselves versus others (i.e., own child, unfamiliar child, unfamiliar adult; Fig. 4-B, Supplement 6). For self versus all others (i.e., own child, unfamiliar, child unfamiliar adult), parents exhibited significantly larger deactivations in left IFG, left precentral gyrus, left middle temporal gyrus/TPJ, and right SFG/dmPFC (p <.001 for all). They exhibited significantly decreased deactivation for self versus an unfamiliar child (p <.001) and adult (p <.001) in opercular part of right IFG and an increased BOLD-response for self versus others (own child, $p = .002$; unfamiliar child, p <.001; unfamiliar adult, p <.001) in triangular part of right IFG and for self versus an unfamiliar child (p <.001) and adult (p <.001) in left middle/inferior occipital gyrus. BOLD-responses in left middle/inferior occipital gyrus and opercular part of right IFG did not significantly differ between own child and self, suggesting that these regions were more sensitive to (personally) familiar faces versus unfamiliar faces.

Finally, we examined whether parents who gazed more towards the eye region contact showed differential neural responses to direct minus averted gaze videos of the targets. We performed regression analyses in SPM for each target separately and tested whether the average percentage of dwell time to the eye region of each target was associated with parents' neural responses to eye contact with each target (Δdirect minus averted gaze trials). These analyses revealed no evidence for neural responses increasing with time spent looking at the eye region after correction for multiple comparisons.

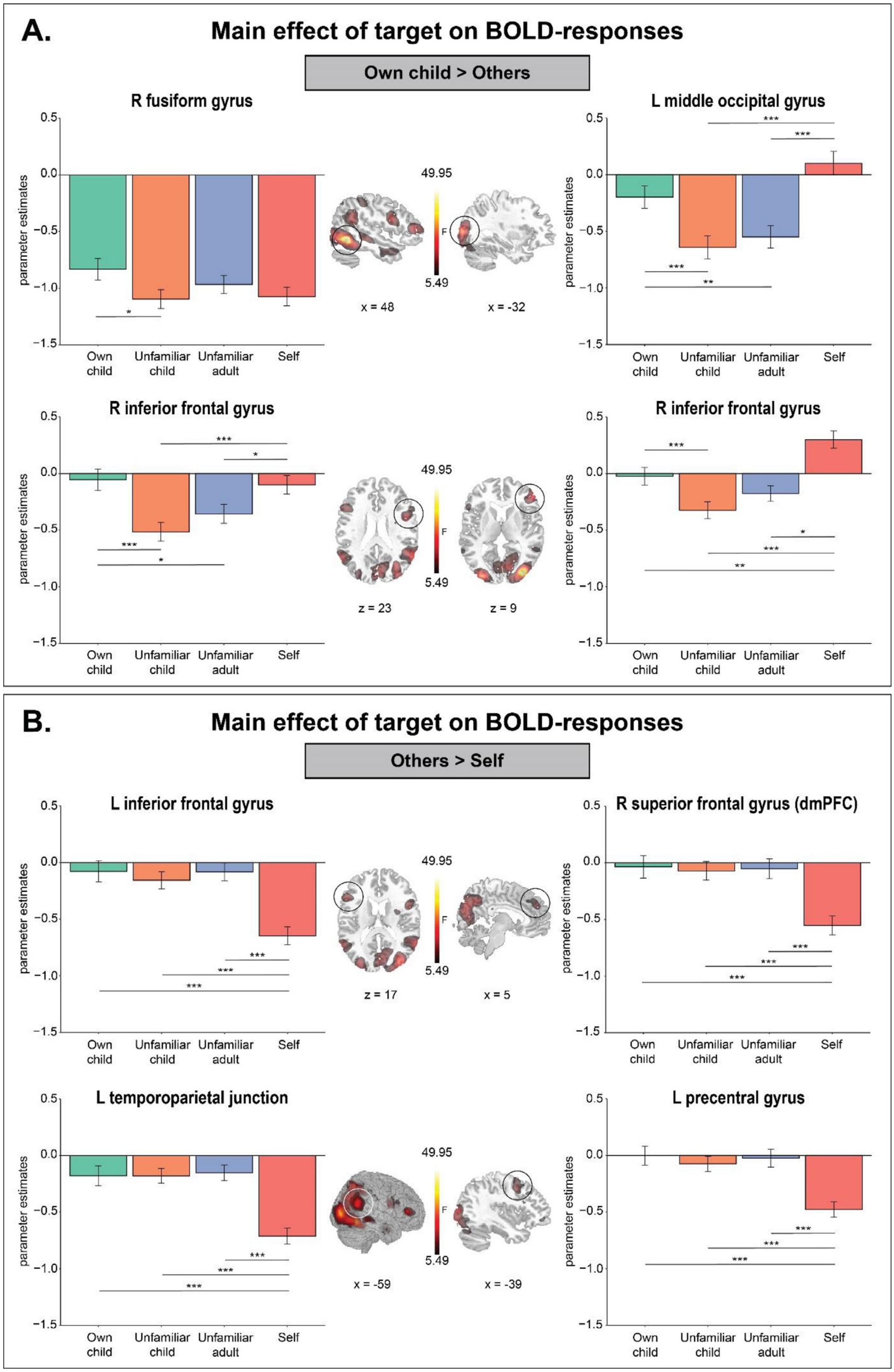

Fig. 4. A whole-brain analysis testing for a main effect of target (i.e., own child, unfamiliar child, unfamiliar adult, and self) on BOLD-responses revealed a set of brain regions sensitive to target identity. Parents (n = 79) showed decreased deactivation in right fusiform gyrus, left middle occipital gyrus, and right IFG to the sight of their own child versus others (A), and to the sight of others (i.e., own child, unfamiliar child, unfamiliar adult) versus self in left IFG, right dmPFC, left TPJ, and left precentral gyrus (B). Error bars represent standard error of the mean. Post-hoc results were Bonferroni corrected and tested in R using generalized linear mixed models. Significant p-values <.05 were indicated by *, p <.01 by **, and p <.001 by ***.

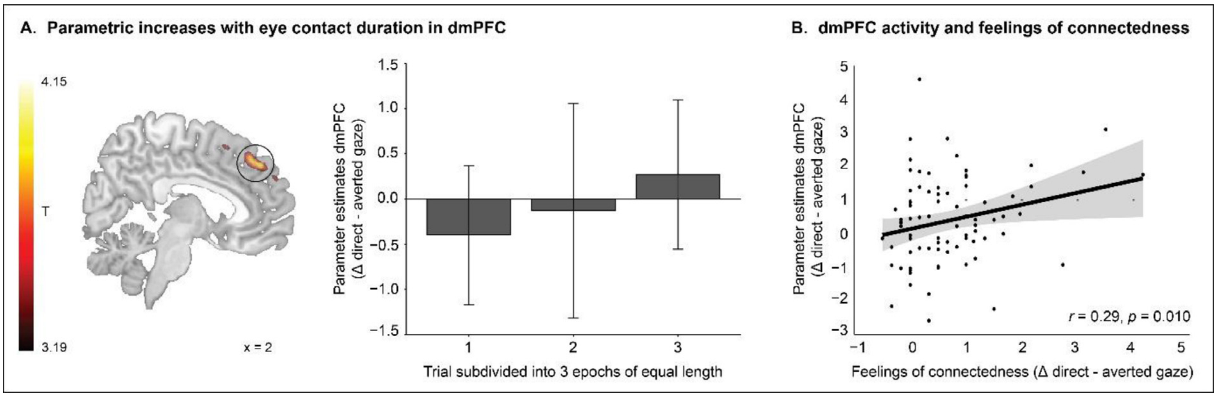

Fig. 5. Prolonged eye contact was associated with parametric increases in right dmPFC, which correlated with increased feelings of connectedness with others (Δ direct – averted gaze videos). We performed a parametric analysis testing for linear increases in neural responses associated with presentation duration of eye contact (Δ direct minus averted gaze). To visualize the parametric effect, we subdivided each video in 3 epochs of equal length and plotted average BOLD-responses in dmPFC for each epoch (A). Correlation analysis testing for the association between individual levels of dmPFC activity and feelings of connectedness in response to eye contact between direct versus averted gaze videos (Δ direct – averted gaze) (B).

3.4. Exploratory analyses

To further explore hypotheses related to prolonged eye contact inducing feelings of connectedness we ran non-preregistered analyses where we explored parametric increases or decreases over the duration of the trial in neural activation specific to eye contact (Δdirect – averted gaze) with another person. For these analyses we focused on conditions where one could make eye contact with another person, collapsing across all ‘other’ conditions (i.e., own child, unfamiliar child, and unfamiliar adult). We split each trial into three epochs of equal length and subsequently tested for parametric increases and decreases with presentation duration [-1 0 1].

A parametric analysis testing for lineair increases in BOLD-response with increased eye contact revealed a significant cluster in right dmPFC (MNI (2, 38, 47), $Z = 4.15$, $p_{\text{cluster-level}} = .004$, Fig. 5-A). An analysis testing for linear decreases in BOLD-response with increased eye contact did not yield significant neural responses at our chosen threshold. To explore whether this potential neural correlate of prolonged eye contact may drive increases in feelings of connectedness, we correlated eye contact related dmPFC activity with self-reported increases in parents’ feelings of connectedness with the targets between direct and averted gaze videos (Δdirect – averted gaze; see Fig. 5-B). This analysis yielded a significant positive association between right dmPFC activity increases and feelings of connectedness with others ($r = .29$, $p = .010$). Together, these results suggest that parents who show enhanced neural activation in dmPFC in response to direct versus averted gaze videos as presentation duration of eye contact increases also showed a greater increase in feelings of connectedness with others after direct versus averted gaze videos.

3.5. Confound analyses

To control for the fact that in two cases two parents of the same adolescent performed the task, we added a covariate to our analyses regarding the self-reported affect ratings and gaze responses of parents, indicating which parents were part of the same family. As this revealed that the data was not nested at the family level, we did not remove these parents from the functional MRI analyses. All outcomes remained significant after controlling for gender of parents and whether parents participated in the study with a child with or without MDD/dysthymia. In addition, all outcomes at the neural level remained significant after controlling for handedness (left/right), current psychopathology (yes/no), and psychotropic medication status (yes/no). Lastly, we checked whether severity of MDD symptoms of parents’ adolescent child have affected how parents respond to direct and averted gaze of the targets. These analyses demonstrated that all previously reported significant results remained significant after controlling for adolescents’ depressive symptoms (i.e., affective, gaze, and neural responses).

4. Discussion

The goal of this study was to investigate neural and affective responses to eye contact with one’s own child and testing the uniqueness of these patterns when comparing them to eye contact with an unfamiliar child and adult. We developed a new fMRI paradigm using direct and averted gaze stimuli of prolonged duration, which allowed us to capture positive affect and feelings of connectedness elicited by eye contact. The results indicate that prolonged eye contact induces positive feelings and feelings of social connectedness. Interestingly, these increases were stronger when making eye contact with unfamiliar others versus one’s own child, probably due to the fact that feelings of connectedness with one’s own child were high at baseline. While we found no robust evidence for neural correlates of direct versus averted gaze when analyzing neural responses across the entire duration of the videos, an exploratory parametric analysis indicated that dmPFC activity linearly increased with the duration of eye contact. Moreover, the increased dmPFC activity correlated positively with self-reported connectedness, suggesting that activity in this region may be related to the increases in feelings of connectedness with others during prolonged eye contact. Finally, our results demonstrated increased neural response to seeing one’s own child versus other people in a network of brain regions previously associated with processing of personally familiar faces (i.e., inferior occipital gyrus and fusiform gyrus) and preparing a communicative (parenting) response, such as the initiation of social interaction (i.e., IFG; Cavallo et al., 2015; Feldman, 2017; Pfeiffer et al., 2013; Taylor et al., 2009).

After looking at prolonged direct versus averted gaze videos participants generally reported to feel more connected and more positive about the targets and reported to have a better mood. When comparing participants’ affective responses after the direct gaze videos of the targets to their responses at baseline, when rating the static pictures, prolonged eye contact resulted in stronger feelings of connectedness and more positive feelings about the others. These findings indicate that looking at prerecorded eye contact videos of prolonged durations can induce positive feelings about others and feelings of connectedness, confirming the validity of our new paradigm to induce positive affiliative reactions. This is in line with our hypotheses and with the literature emphasizing enhanced positive affective responses to eye contact (Hietanen, 2018).

In terms of BOLD-responses, our results indicated no robust evidence of differences in neural processing between direct and averted gaze videos. However, most studies that found differential neural responses to direct versus averted gaze used stimuli with a short duration (< 2 s), and merely focused on the impact of gaze direction on facial recognition processes, while we chose to use prolonged eye contact trials (16-38 s) to capture neural processes associated with affiliative responses elicited by eye contact. Interestingly, our paradigm enabled us to examine which brain regions increase or decrease in activity over time as the duration of eye contact increases. When we performed exploratory parametric analyses to capture this process at the neural level over the course of the trials, we found an increase in dmPFC activity co-varying with increased presentation time of direct (versus averted) gaze. The dmPFC has been consistently found to play a role in theory of mind and mentalizing (Bzdok et al., 2012), suggesting that prolonged eye contact might involve greater engagement in such higher-order cognitive processes. Moreover, the increased dmPFC activation was associated with feelings of connectedness towards others after direct gaze videos specifically, indicating that parents who showed greater increases in dmPFC activation as eye contact duration increases also reported higher levels of connectedness to others after exposure to direct (versus averted) gaze. Moreover, this is finding is in line with a study of Cavallo et al. (2015) who found that the dmPFC was specifically activated in case participants reciprocated the direct gaze of the target to establish a mutual gaze.

Independent of gaze direction, parents showed a decreased deactivation in middle/inferior occipital gyrus and fusiform gyrus in response to the sight of their own child versus others. Prior work implicated these regions in processing of personally familiar stimuli, such as faces of parents and romantic partners (Taylor et al., 2009). Furthermore, parents showed decreased deactivation in IFG, a brain region involved in the automated internal representation of others' mental states and is part of the mirror-neuron system, which is directly linked to empathy (Feldman, 2017). Decreased deactivation in this region has consistently been linked to parental caregiving and is found in parents when presented with various types of stimuli of their own child versus an unfamiliar child (i.e., cry, imagined situation, pictures, video fragments) (Bornstein et al., 2017; Feldman, 2015; Feldman, 2017; Wever et al., 2021). Taken together, these findings indicate robust pattern of activation for the sight of parents' own adolescent child versus others in cortical face processing and the mirror-neuron system.

Regarding parents' responses to the sight of an unfamiliar child versus an unfamiliar adult, we did not find any differences at the subjective nor the neural level. This was not in line with our hypothesis based on the prior findings of Leibenluft et al. (2004), who found increased neural responses in parents in fusiform gyrus, intraparietal sulcus, precuneus, and posterior STS to the sight of an unfamiliar child versus an unfamiliar adult. One possible explanation is that in the current study we presented parents with prolonged video stimuli, while Leibenluft et al. (2004) used static pictures that lasted only 1.5 s. This might suggest that the differential neural responses to the sight of an unfamiliar child versus adult might lie in the initial decoding phase of face perception, shortly after the start of the presentation of the face, rather than in the later, more evaluative, phase, when more complex socio-emotional aspects of eye contact are involved (i.e., motivation of the gazer, mentalizing, theory-of-mind), which may not differ between an unfamiliar child and adult.

An innovative aspect of the current study was the assessment of parents' gaze during the task in the scanner to assess how much eye contact they *actually* made with the targets in the videos. Corroborating findings from experimental studies (outside the scanner), we found that parents gazed more towards the eye region of the targets during direct versus averted gaze videos (Hessels, 2020; Hietanen, 2018; Kleinke, 1986). This indicates that direct gaze attracts and maintains people's attention more than averted gaze. Regarding the distinct targets in the videos, parents made more eye contact with an unfamiliar adult versus their own child or an unfamiliar child, while no differences were found in the amount of gaze towards the (whole) face of the targets. A possible explanation for this effect might be that eye contact among adults may also serve functions other than affiliation. For example, eye contact is used for defining a hierarchy (Tang & Schmeichel, 2015). Such processes may be less relevant when adults make eye contact with a child. Another interesting finding was that despite the instructions of making eye contact with the persons in the videos, participants only made eye contact for 30-40% of the time, which may illustrate a deeply ingrained notion of how much eye gazing is appropriate during social interactions. To date, very little is known about the underlying mechanism of this very basic and automated dynamic process of making and breaking eye contact during social interactions and future studies in this direction should focus on the underlying mechanism of process, which likely plays an important role in the communicative function of eye contact.

The main reason for including the self condition in which parents were presented with videos of their own prolonged direct and averted gaze was to disentangle whether the neural responses that we found were uniquely social in nature (i.e., in interaction with other people) rather than lower-level perceptual responses of seeing a face. Our results demonstrated that videos containing a social "other" (versus the self) reliably engaged regions in the Theory of Mind and Empathy networks (Bzdok et al., 2012), including TPJ, dmPFC, and IFG. Interestingly, videos with a direct (versus averted) gaze of themselves increased parents own mood in a similar way as the videos of others. Moreover, parents did not show substantial differences in eye gaze behavior towards their own eye regions versus the eye region of the others, indicating that they were equally able to make eye contact with themselves during the videos as they did with the other targets. Taken together, the self-condition enabled us to uncover unique effects of eye contact with other people on positive affect and the involvement of a unique set of brain regions associated with making eye contact with others. Interestingly, the results regarding the self-condition illustrate that making eye contact with oneself can also have a mood-boosting effect, which is an interesting avenue for future research and clinical interventions.

The newly developed eye contact task benefits from a personalized task design, allowing us to examine parents' affective, gaze, and neural responses to prolonged eye contact with one's own child and others, which generalizes across mothers and fathers. Nevertheless, this study is not without limitations. Although the prolonged duration of the video stimuli in the current study allowed us to capture affiliative responses elicited by eye contact, it probably limited the detection of processes that happened on a shorter time scale after stimulus onset, such as the recognition of gaze direction. As a next step, it would be of great interest to investigate how parents respond to video stimuli of their own child and others comparing various presentation durations. In addition, the video stimuli in the current task are closer to natural interactions compared to the static pictures that have been used before, but the use of pre-recorded video stimuli, in contrast to real-life gaze encounters, might have elicited responses that are not identical to eye-to-eye contact during live interactions. Future studies should take a next step in studying eye contact during live interactions to assess how people respond to prolonged eye contact during real-life interactions. This is emphasized by studies showing that prolonged eye contact elevated participants' levels of arousal only in case of real-life bidirectional eye contact (Hietanen et al., 2020; Jarick & Bencic, 2019). As we have not assessed whether the prolonged video stimuli of direct gaze increased parents' levels of arousal in the task, this would be an interesting addition to the current paradigm. Notwithstanding these limitations, our findings show that the prolonged eye contact stimuli used in the current study successfully induced affiliative responses, including positive affect and social connectedness and increased dmPFC activation that covaried with presentation duration of direct gaze. Lastly, by performing a parametric analysis over the duration of the trials we assumed that the increase in dmPFC activation is linear, while in fact we do not know the exact shape of this response. Moreover, since we were agnostic about the mapping between neural responses and the BOLD-response associated with increased prolonged exposure, we used a canonical hemodynamic response function. Also, it is of note that the subdivision of trial duration in three epochs of equal length to assess changes in BOLD-responses over time is relatively arbitrary and a different subdivision might have possibly led to a different outcome. Although this finding is in line with prior research (Cavallo et al., 2015) and the expectation that higher-order social processes, such as mentalizing, starts to become increasingly involved as the duration of eye contact continues, it needs to be interpreted with caution and future studies should replicate this.

5. Conclusion

We developed a personalized fMRI paradigm including dynamic stimuli, suited to measure affective, gaze, and neural responses to prolonged eye contact. Our results show that our task enhances parents' positive feelings about the targets and their feelings of connectedness. The multimethod approach did not only inform us on how parents respond to eye contact at the level of the brain, but gave additional insight into subjective feelings and actual eye gazing patterns. Although at the subjective level parents' showed largest increases in positive affect in response to eye contact with unfamiliar others compared to their own child, we did not find reliable evidence of this pattern at the level of their gaze behavior or neural responses. We found robust evidence of parents' brains differentiating between the sight of their own child versus unfamiliar others. These results provide new insights into the impact of the gaze direction, the identity of the gazer, and the duration of eye contact on the processing of prolonged eye contact in parents, both within and beyond the parent-child context. We used it to examine neural and affective responses to eye contact with one's own adolescent child, but it could be applied to many different contexts and research questions, such as the impact of eye contact with parents or peers during adolescence. This study paves the way for the development of interventions for those having difficulties connecting with others via eye contact (for example, individuals with autism or social anxiety) or in whom affiliative processes are disrupted.

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Data/code availability statement

The de-identified data, analysis scripts and materials for this study are available on DataverseNL and the MRI data are available on NeuroVault (https://neurovault.org/collections/12205/). All study measures and hypotheses were preregistered at Open Science Framework prior to data analyses (https://osf.io/54nky/). For any questions or additional material, please contact the corresponding author.

Declaration of competing interest

None.

Credit authorship contribution statement

Mirjam C.M. Wever: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing – original draft, Visualization. **Lisanne A.E.M. van Houtum:** Conceptualization, Software, Investigation. **Loes H.C. Janssen:** Investigation. **Wilma G.M. Wentholt:** Investigation. **Iris M. Spruit:** Methodology, Software. **Marieke S. Tollenaar:** Conceptualization, Writing – review & editing, Supervision. **Geert-Jan Will:** Conceptualization, Methodology, Software, Investigation, Writing – review & editing, Supervision. **Bernet M. Elzinga:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2022.119463.

References

Abraham, E., Raz, G., Zagoory-Sharon, O., Feldman, R., 2018. Empathy networks in the parental brain and their long-term effects on children's stress reactivity and behavior adaptation. Neuropsychologia 116, 75–85. doi:10.1016/j.neuropsychologia.2017.04.015.

Argyle, M., Lefebvre, L., Cook, M., 1974. The meaning of five patterns of gaze. European journal of social psychology 4 (2), 125–136. doi:10.1002/ejsp.2420040202.

Ashburner, J., 2007. A fast diffeomorphic image registration algorithm. Neuroimage 38 (1), 95–113. doi:10.1016/j.neuroimage.2007.07.007.

Atzil, S., Hendler, T., Feldman, R., 2011. Specifying the neurobiological basis of human attachment: brain, hormones, and behavior in synchronous and intrusive mothers. Neuropsychopharmacology 36 (13), 2603. doi:10.1038/npp.2011.172.

Barrett, J., Wonch, K.E., Gonzalez, A., Ali, N., Steiner, M., Hall, G.B., Fleming, A.S., 2012. Maternal affect and quality of parenting experiences are related to amygdala response to infant faces. Social neuroscience 7 (3), 252–268. doi:10.1080/17470919.2011.609907.

Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R.H.B., Singmann, H., Dai, B., Scheipl, F., Grothendieck, G., 2012. Package 'lme4'. R Foundation for Statistical Computing. CRAN, Vienna, Austria.

Bojko, A., 2013. Eye tracking the user experience: A practical guide to research. Rosenfeld Media.

Bornstein, M.H., Putnick, D.L., Rigo, P., Esposito, G., Swain, J.E., Suwalsky, J.T., Su, X., Du, X., Zhang, K., Cote, L.R., 2017. Neurobiology of culturally common maternal responses to infant cry. Proceedings of the National Academy of Sciences 114 (45), E9465–E9473. doi:10.1073/pnas.1712022114.

Brooks, C.I., Church, M.A., Fraser, L., 1986. Effects of duration of eye contact on judgments of personality characteristics. The Journal of Social Psychology 126 (1), 71–78. doi:10.1080/00224545.1986.9713572.

Bzdok, D., Schilbach, L., Vogeley, K., Schneider, K., Laird, A.R., Langner, R., Eickhoff, S.B., 2012. Parsing the neural correlates of moral cognition: ALE meta-analysis on morality, theory of mind, and empathy. Brain Structure and Function 217 (4), 783–796. doi:10.1007/s00429-012-0380-y.

Cavallo, A., Lungu, O., Becchio, C., Ansuini, C., Rustichini, A., Fadiga, L., 2015. When gaze opens the channel for communication: Integrative role of IFG and MPFC. Neuroimage 119, 63–69. doi:10.1016/j.neuroimage.2015.06.025.

Cowan, D.G., Vanman, E.J., Nielsen, M., 2014. Motivated empathy: the mechanics of the empathic gaze. Cognition and Emotion 28 (8), 1522–1530. doi:10.1080/02699931.2014.890563.

Elmadih, A., Wan, M.W., Downey, D., Elliott, R., Swain, J.E., Abel, K.M., 2016. Natural variation in maternal sensitivity is reflected in maternal brain responses to infant stimuli. Behavioral neuroscience 130 (5), 500. doi:10.1037/bne0000161.

Emery, N.J., 2000. The eyes have it: the neuroethology, function and evolution of social gaze. Neuroscience & Biobehavioral Reviews 24 (6), 581–604. doi:10.1016/S0149-7634(00)00025-7.

Eskritt, M., Lee, K., 2007. Preschoolers' use of eye-gaze for" mind reading" in Gaze-following: Its development and significance. Psychology Press.

Feldman, R., 2015. The adaptive human parental brain: implications for children's social development. Trends in neurosciences 38 (6), 387–399. doi:10.1016/j.tins.2015.04.004.

Feldman, R., 2017. The neurobiology of human attachments. Trends in cognitive sciences 21 (2), 80–99. doi:10.1016/j.tics.2016.11.007.

Gallagher, S., 2014. In your face: transcendence in embodied interaction. Frontiers in human neuroscience 8, 495. doi:10.3389/fnhum.2014.00495.

Hessels, R.S., 2020. How does gaze to faces support face-to-face interaction? A review and perspective. Psychonomic Bulletin & Review 1–26. doi:10.3758/s13423-020-01715-w.

Hietanen, J.K., 2018. Affective eye contact: an integrative review. Frontiers in Psychology 9, 1587. doi:10.3389/fpsyg.2018.01587.

Hietanen, J.K., Helminen, T.M., Kiilavuori, H., Kylliäinen, A., Lehtonen, H., Peltola, M.J., 2018. Your attention makes me smile: Direct gaze elicits affiliative facial expressions. Biological psychology 132, 1–8. doi:10.1016/j.biopsycho.2017.11.001.

Hietanen, J.O., Peltola, M.J., Hietanen, J.K., 2020. Psychophysiological responses to eye contact in a live interaction and in video call. Psychophysiology 57 (6), e13587. doi:10.1111/psyp.13587.

Jarick, M., Bencic, R., 2019. Eye contact is a two-way street: Arousal is elicited by the sending and receiving of eye gaze information. Frontiers in Psychology 10, 1262. doi:10.3389/fpsyg.2019.01262.

Kaufman, J., Birmaher, B., Brent, D., Rao, U., Ryan, N., 1996. Kiddie-Sads-present and Lifetime version (K-SADS-PL). University of Pittsburgh, School of Medicine, Pittsburgh doi:10.1097/00004583-199707000-00021.

Kellerman, J., Lewis, J., Laird, J.D., 1989. Looking and loving: The effects of mutual gaze on feelings of romantic love. Journal of research in personality 23 (2), 145–161. doi:10.1016/0092-6566(89)90020-2.

Kiilavuori, H., Sariola, V., Peltola, M.J., Hietanen, J.K., 2021. Making eye contact with a robot: Psychophysiological responses to eye contact with a human and with a humanoid robot. Biological psychology 158, 107989. doi:10.1016/j.biopsycho.2020.107989.

Kleinke, C.L., 1986. Gaze and eye contact: a research review. Psychological Bulletin 100 (1), 78. doi:10.1037/0033-2909.100.1.78.

Kroenke, K., Spitzer, R.L., Williams, J.B., 2001. The PHQ-9: validity of a brief depression severity measure. Journal of general internal medicine 16 (9), 606–613. doi:10.1046/j.1525-1497.2001.016009606.x.

Kuo, P.X., Carp, J., Light, K.C., Grewen, K.M., 2012. Neural responses to infants linked with behavioral interactions and testosterone in fathers. Biological psychology 91 (2), 302–306. doi:10.1016/j.biopsycho.2012.08.002.

Kuzmanovic, B., Georgescu, A.L., Eickhoff, S.B., Shah, N.J., Bente, G., Fink, G.R., Vogeley, K., 2009. Duration matters: dissociating neural correlates of detection and evaluation of social gaze. Neuroimage 46 (4), 1154–1163. doi:10.1016/j.neuroimage.2009.03.037.

Leibenluft, E., Gobbini, M.I., Harrison, T., Haxby, J.V., 2004. Mothers' neural activation in response to pictures of their children and other children. Biological psychiatry 56 (4), 225–232. doi:10.1016/j.biopsych.2004.05.017.

Lenzi, D., Trentini, C., Pantano, P., Macaluso, E., Iacoboni, M., Lenzi, G., Ammaniti, M., 2009. Neural basis of maternal communication and emotional expression processing during infant preverbal stage. Cerebral cortex 19 (5), 1124–1133. doi:10.1093/cercor/bhn153.

Montemayor, R., 1983. Parents and adolescents in conflict: All families some of the time and some families most of the time. The Journal of Early Adolescence 3 (1-2), 83–103. doi:10.1177/027243168331007.

Montemayor, R., 1986. Family variation in parent-adolescent storm and stress. Journal of adolescent research 1 (1), 15–31. doi:10.1177/074355488611003.

Montgomery, D.E., Back, L.M., Moran, C., 1998. Children's use of looking behavior as a cue to detect another's goal. Child development 69 (3), 692–705. doi:10.1111/j.1467-8624.1998.tb06237.x.

Petrowski, K., Wintermann, G.-B., Hübner, T., Smolka, M.N., Donix, M., 2019. Neural Responses to Faces of Attachment Figures and Unfamiliar Faces: Associations With Organized and Disorganized Attachment Representations. The Journal of nervous and mental disease 207 (2), 112–120. doi:10.1097/NMD.0000000000000931.

Pfeiffer, U.J., Vogeley, K., Schilbach, L., 2013. From gaze cueing to dual eye-tracking: novel approaches to investigate the neural correlates of gaze in social interaction. Neuroscience & Biobehavioral Reviews 37 (10), 2516–2528. doi:10.1016/j.neubiorev.2013.07.017.

R Core Team, 2013. R: A language and environment for statistical computing.

Ramon, M., Gobbini, M.I., 2018. Familiarity matters: A review on prioritized processing of personally familiar faces. Visual Cognition 26 (3), 179–195. doi:10.1080/13506285.2017.1405134.

Regenbogen, C., Schneider, D.A., Finkelmeyer, A., Kohn, N., Derntl, B., Kellermann, T., Gur, R.E., Schneider, F., Habel, U., 2012. The differential contribution of facial expressions, prosody, and speech content to empathy. Cognition & Emotion 26 (6), 995–1014. doi:10.1080/02699931.2011.631296.

Revelle, W., 2012. Procedures for psychological, psychometric, and personality research. Acesso em 9.

Robson, K.S., 1967. The role of eye-to-eye contact in maternal-infant attachment. Journal of Child Psychology and Psychiatry 8 (1), 13–25. doi:10.1111/j.1469-7610.1967.tb02176.x.

Saito, D.N., Tanabe, H.C., Izuma, K., Hayashi, M.J., Morito, Y., Komeda, H., Uchiyama, H., Kosaka, H., Okazawa, H., Fujibayashi, Y., 2010. Stay tuned": inter-individual neural synchronization during mutual gaze and joint attention. Frontiers in integrative neuroscience 4, 127. doi:10.3389/fnint.2010.00127.

Senju, A., Johnson, M.H., 2009. The eye contact effect: mechanisms and development. Trends in cognitive sciences 13 (3), 127–134. doi:10.1016/j.tics.2008.11.009.

Shimon-Raz, O., Salomon, R., Bloch, M., Romano, G.A., Yeshurun, Y., Yaniv, A.U., Zagoory-Sharon, O., Feldman, R., 2021. Mother brain is wired for social moments. Elife 10, e59436.

Steinberg, L., Silk, J.S., 2002. Parenting adolescents. Handbook of parenting 1, 103–133.

Tang, D., Schmeichel, B.J., 2015. Look me in the eye: Manipulated eye gaze affects dominance mindsets. Journal of Nonverbal Behavior 39 (2), 181–194. doi:10.1007/s10919-015-0206-8.

Taylor, M.J., Arsalidou, M., Bayless, S.J., Morris, D., Evans, J.W., Barbeau, E.J., 2009. Neural correlates of personally familiar faces: parents, partner and own faces. Human brain mapping 30 (7), 2008–2020. doi:10.1002/hbm.20646.

Ulmer-Yaniv, A., Waidergoren, S., Shaked, A., Salomon, R., Feldman, R., 2021. Neural representation of the parent–child attachment from infancy to adulthood. Social Cognitive and Affective Neuroscience.

van Houtum, L.A., Wever, M.C., Janssen, L.H., van Schie, C.C., Will, G.-J., Tollenaar, M.S., Elzinga, B.M., 2021. Vicarious praise and pain: parental neural responses to social feedback about their adolescent child. Social Cognitive and Affective Neuroscience 16 (4), 406–417. doi:10.1093/scan/nsab004.

Viola, P., Jones, M., 2001. Rapid object detection using a boosted cascade of simple features. In: Proceedings of the 2001 IEEE computer society conference on computer vision and pattern recognition. CVPR 2001.

Wan, M.W., Downey, D., Strachan, H., Elliott, R., Williams, S.R., Abel, K.M., 2014. The neural basis of maternal bonding. PLoS one 9 (3). doi:10.1371/journal.pone.0088436.

Wever, M.C., van Houtum, L.A., Janssen, L.H., Will, G.-J., Tollenaar, M.S., Elzinga, B.M., 2021. Neural signatures of parental empathic responses to imagined suffering of their adolescent child. Neuroimage 232, 117886. doi:10.1016/j.neuroimage.2021.117886.

Wickham, H., Chang, W., Wickham, M.H., 2016. Package 'ggplot2'. *Create Elegant Data Visualisations Using the Grammar of Graphics*. Version 2 (1), 1–189.