



Neural processing of the own child's facial emotions in mothers with a history of early life maltreatment

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Abstract

Early life maltreatment (ELM) has long-lasting effects on social interaction. When interacting with their own child, women with ELM often report difficulties in parenting and show reduced maternal sensitivity. Sensitive maternal behavior requires the recognition of the child's emotional state depicted in its facial emotions. Based on previous studies, it can be expected that ELM affects the neural processing of facial emotions by altering activation patterns in parts of the brain's empathy and mentalizing networks. However, so far studies have focused on the processing of standardized, adult facial emotions. Therefore, the current study investigated the impact of ELM on the processing of one's own child's facial emotions using functional magnetic resonance imaging. To achieve this, 27 mothers with and 26 mothers without a history of ELM (all without current mental disorders and psychopharmacological treatment) took part in an emotional face recognition paradigm with happy, sad, and neutral faces of their own and an unknown primary school-aged child of the same age and sex. We found elevated activations in regions of the mentalizing (superior temporal sulcus, precuneus) and mirror neuron (inferior parietal lobule) networks as well as in the visual face processing network (cuneus, middle temporal gyrus) in mothers with ELM compared to the non-maltreated mothers in response to happy faces of their own child. This suggests a more effortful processing and cognitive empathic mentalizing of the own child's facial happiness in mothers with ELM. Future research should address whether this might indicate a compensatory recruitment of mentalizing capacities to maintain maternal sensitivity.

Keywords Trauma · Physical and sexual abuse · Maternal brain · Facial emotion recognition · Functional magnetic resonance imaging · Mentalizing

Introduction

Early life maltreatment (ELM) such as sexual or physical abuse is highly prevalent [1, 2]. Its consequences range from an increased risk for cardiovascular dysfunctioning [3] to

an increased risk for mental disorders in general, including non-psychotic disorders like depression [4], various anxiety disorders [5], or borderline personality disorder [6], as well as psychotic disorders [7]. Beyond this, women with ELM often report difficulties in parenting their children. Empirical evidence confirms more impulsive, intrusive, and hostile behaviors [8, 9] as well as less positive parent–child interactions [10] along with reduced confidence in parenting competences [11] in women with experiences of ELM. Consistent with this, data from our own research group points to reduced sensitivity of maltreated mothers when interacting with their child [12–14], resulting in behavior problems and deficits in social competences of the children [15, 16].

One important aspect of sensitive parenting is the fast and accurate recognition of and response to a child's emotional cues, such as facial emotions. Facial emotions of infants and children not only convey information that facilitates social communication, but are also particularly salient and

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rewarding cues for their parents. The neural correlates of facial processing involve regions responsible for the visual face analysis including the inferior occipital gyri, the lateral fusiform gyri, and the superior temporal sulci as well as regions representing the emotional meaning of facial expressions, such as the amygdala, the insula, and other parts of the limbic system [17]. ELM-related alterations in the neural correlates of facial emotion processing have been confirmed in a recent meta-analysis [18]. Summarizing the results of 20 original studies, the authors of this meta-analysis found enhanced amygdala responses to facial emotions in individuals with vs. without ELM. Furthermore, ELM was associated with enhanced activations in the superior temporal gyrus, the parahippocampal gyrus, and the insula suggesting ELM-related alterations in regions that belong to the empathy and the mentalizing networks. Importantly, most of these studies have focused on the processing of adult facial emotions, mainly using pictures from standardized facial databases.

As noted above, one's own child's face is a particularly salient cue for parents. On a neural level, a child's compared to an adult's face elicits stronger activation in the fusiform gyri, the middle occipital gyri, the superior temporal gyri, the supplementary motor area, the pre- and the postcentral gyri, as well as in the amygdala (for review, see [19]). Furthermore, mothers show enhanced activations to facial emotions of their own vs. an unknown infant or child in regions of the reward system including the ventral tegmental area/substantia nigra and the striatum, regions which are involved in the processing and regulation of affect, such as the medial prefrontal cortex, the anterior cingulate cortex, the insula, and the orbitofrontal cortex, as well as regions of the mentalizing network (superior temporal sulcus, anterior paracingulate cortex) [20–22]. With regard to facial emotion processing, one previous study found elevated activations in the parietal cortex, the insula, the striatum, the temporal gyri, as well as the medial and the lateral frontal cortices in mothers viewing positive compared to neutral facial expressions of their own babies [23]. Recently, Kluczniok and colleagues [24] investigated healthy mothers' processing of happy and sad vs. neutral faces of their own 5- to 20-year-old children. They found increased activations in a network comprising reward- and empathy-related brain regions, such as the parahippocampal gyrus, the superior temporal gyrus, the inferior parietal gyrus, the cuneus, the hippocampus, and the insula for happy faces and in a network involving the anterior cingulate cortex, the hippocampus, the orbitofrontal gyrus, the insula, and the amygdala in response to sad expressions of one's own vs. an unfamiliar child.

With regard to mothers with ELM, recent data from our own group suggest a particular deficit in the processing of positive emotional cues. When imagining pleasant vs. conflictual interactions with their own child, mothers with ELM

showed reduced activations in the insula, the amygdala, the hippocampus, the parahippocampal gyrus, and the supplementary motor area compared to mothers without ELM [25], indicating reduced salience and behavioral relevance of pleasant and joyful interactions with their child. Moreover, in a partly overlapping sample, we examined structural neural correlates of sensitive mother–child interactions and found a positive association between gray matter volume (GMV) in regions of the mentalizing network (associated with cognitive empathy) and maternal sensitivity in mothers with ELM, while in mothers without ELM maternal sensitivity was positively associated with GMV in regions of the affective empathy network [14]. Thus, it seems that ELM-exposed mothers who maintain the ability to interact sensitively with their child compensatorily recruit cognitive empathic capabilities.

Taken together, research up to now shows an impact of ELM on neural processing of facial emotions and ELM-associated alterations of maternal neural responsiveness. Thus, a possible reason for parenting difficulties of women with ELM might be an altered processing of their child's facial emotions. However, the impact of ELM on the maternal neural processing of facial emotions of their own child has not been investigated so far. Hence, the aim of the present study was to examine whether a history of ELM alters maternal facial emotion processing.

In the present study, we investigated maternal neural responses to their own child's facial emotions in mothers with and without ELM using an emotional face recognition functional imaging paradigm (children 6–12 years old). Considering previous work from our group showing different neural activations of ELM mothers and control mothers without ELM in response to pleasant mother–child interactions, we were particularly interested in the maternal response to happy faces of their own child. Based on the study by Kluczniok et al. [24], which used the same paradigm in healthy mothers, we first expected all mothers to activate brain areas processing reward and emotion in response to happy faces. Since we found mothers with ELM to show altered neural activation in response to pleasant interactions with their own child compared to control mothers without ELM [25], we expected mothers with ELM to show alterations in processing their child's happy face. Namely, with regard to results suggesting that cognitive empathic capabilities play a particularly important role in sensitive maternal behavior of mothers with ELM [14], we expected them to show stronger activations in regions of the mentalizing network (especially, superior temporal gyrus) in response to happy faces of their child compared to mothers without ELM. In addition, we expected mothers with ELM to show lower activity in the salience network in response to happy facial emotions of their child. We also explored whether we could find a different activation pattern

in mothers with and without ELM in response to sad faces of their child. Lastly, we explored whether ELM-exposed mothers compared to mothers without ELM would respond less quickly and correctly when classifying the child's facial emotion.

Methods

Participants

$N=27$ mothers with ELM (ELM) and $N=26$ control mothers without a history of ELM (CON) and their 6- to 12-year-old children participated in the study. Due to technical malfunctioning, behavioral data were missing for $N=3$ mothers in the emotional face recognition paradigm and $N=9$ mothers in the picture rating task. Exclusion criteria consisted of any current mental disorders, current depressiveness of clinical relevance (i.e., HAM-D values > 10), lifetime diagnosis of schizophrenia, schizoaffective or bipolar disorders, substance abuse in the last 6 months, neurological disorders, current psychotropic medication, severe medical illness of mother or child, and mother and child not living together. Additionally, CON were excluded if they have had any lifetime mental disorder.

While none of the mothers had a current mental disorder, 12 ELM mothers had a lifetime diagnosis ($N=5$ major depressive episode (MDE), $N=1$ MDE and panic disorder, $N=1$ MDE and post-traumatic stress disorder (PTSD), $N=1$ MDE and bulimia nervosa, $N=1$ PTSD, $N=1$ bulimia nervosa, $N=1$ panic disorder). The groups were matched for age of mother and child, sex of child, and years of maternal education (for details, see Table 1). Although groups differed significantly with regard to HAM-D values ($p < 0.05$), none of the mothers had clinically relevant values (ELM: mean (M) 2.9, standard deviation (SD) 3.4; CON: M=0.8, SD 1.3) or fulfilled criteria of a current depressive episode. Mean HAM-D values of both groups were in a very low normal range.

The present study was performed within the framework of the UBICA study (Understanding and Breaking the Intergenerational Cycle of Abuse). The UBICA study is a multi-center study investigating the effects of maternal ELM on mother–child interaction and child well-being and development. Thus, samples across UBICA studies show overlap in participants. The study was performed in accordance with the Declaration of Helsinki and approved by the local ethics committee of the Faculty of Medicine, University of Heidelberg. Participants gave written informed consent prior to their participation and received monetary compensation.

Experimental procedure

All mothers attended two appointments: the first appointment comprised the diagnostic assessments including clinical interviews, while structural and functional magnetic resonance imaging (MRI) took place at the second appointment.

Measures

Early life maltreatment was defined as physical and/or sexual abuse before the age of 18 years according to the Childhood Experience of Care and Abuse Interview [26], which is regarded as the gold standard in retrospective evaluation of childhood maltreatment [27]. The international neuropsychiatric interview (M.I.N.I., [28]) and the International Personality Disorder Examination (IPDE; [29]) were used to assess current and lifetime axis I disorders and borderline, antisocial, and avoidant personality disorders. Furthermore, current depressiveness was measured with the Hamilton Rating Scale for Depression (HAM-D [30]). All interviews were conducted by qualified and trained diagnosticians (MSc level in psychology and extensive training prior to the study).

Table 1 Demographic data

	Groups		Group comparisons	
	ELM ($N=27$) M \pm SD/ N , %	CON ($N=26$) M \pm SD/ N , %	t/χ^2 (df)	p
Mother				
Age (years)	39.2 \pm 7.2	39.6 \pm 4.9	-0.096 (51)	0.924
Years of education	17.4 \pm 4.1	16.3 \pm 3.2	1.156 (51)	0.253
Child				
Age (years)	8.2 \pm 1.2	7.9 \pm 1.2	0.904 (45)	0.370
Sex: m/f	52%/48%	50%/50%	0.018 (1)	0.893

ELM mothers with early life maltreatment, CON mothers without early life maltreatment, M mean, SD standard deviation, m male, f female

Emotional face recognition paradigm

The paradigm followed a 3×2 design with the two factors facial emotion (happy, sad, neutral) and familiarity of the depicted child (own, unknown). In two experimental runs, each mother was presented a total of 180 pictures displaying happy, sad, and neutral faces of her own and an age- and sex-matched unknown child. To maintain attention toward the stimuli, mothers were instructed to classify each facial emotion as fast and correctly as possible by pressing a corresponding button. The facial pictures were extracted from videos recorded while the children saw age-appropriate movie clips with happy or sad content. Pictures were cut to the shape of an ellipse, grayscale, and placed in front of a gray background. They were assigned to one of the three emotion categories based on ratings of three independent female raters. Pictures were presented in a pseudorandomized order (< 4 sequential presentations of the same affect and familiarity) and each individual picture was shown three times during the whole task. Each run started with the presentation of a fixation cross (3 s), followed by a 2 s presentation of a child's face and a jittered inter-stimulus interval (2–6 s). The task started with a written instruction and lasted for approximately 17 min in total. After the MRI task, participants were asked to rate the arousal and valence of each facial emotion outside the MR scanner on a seven-point scale (picture-rating task).

MRI data acquisition

Functional MRI (fMRI) was performed in a 3-T whole-body MR scanner (Tim Trio; Siemens, Germany) equipped with a 32-channel head coil. 33 transverse slices (slice thickness 3 mm) were acquired in each volume. A T2*-sensitive gradient echo-planar imaging (EPI) sequence was used (TR 2000 ms, TE 30 ms; flip angle 78° ; FOV = 192×192 mm; in-plane resolution 3×3 mm). Additionally, isotropic high-resolution ($1 \times 1 \times 1$ mm³) structural images were recorded using a T1-weighted sagittally oriented MPRAGE sequence.

Data analyses

Demographic data

Group differences (ELM vs. CON) in demographic data were analyzed with two-sample *t* tests for continuous data and Chi² tests for categorical data.

Behavioral data

Behavioral data comprised reaction times and error rates from the emotional face recognition paradigm as well as valence and arousal ratings from the picture-rating task.

Reaction times and error rates of ± 3 SD were classified as outliers resulting in the exclusion of $N = 4$ mothers from the behavioral analysis. Furthermore, only reaction times of correct answers were analyzed. Reaction times, error rates, and valence and arousal ratings were analyzed with separate $2 \times 3 \times 2$ repeated-measures analyses of variance with the between-subject factor group (ELM vs. CON) and the within-subject factors facial affect (happy, sad, neutral) and familiarity (own vs. unfamiliar). Where appropriate, we applied the Greenhouse–Geisser procedure to correct for potential violations of the sphericity assumption. We employed a two-tailed $p < 0.05$ for all statistical analyses. In cases of significant effects, we used Bonferroni corrected *t* tests as post hoc tests.

fMRI data

Statistical parametric mapping (SPM8, Wellcome Department of Imaging Neuroscience, London) was used for fMRI data preprocessing and analyses. Standard preprocessing routine included slice timing, realignment with unwarping, co-registration to the individual segmented anatomical image, spatial normalization to the Montreal Neurological Institute (MNI) space, resampling with a voxel size of $3 \times 3 \times 3$ mm³, and smoothing by a three-dimensional Gaussian kernel (full width half maximum, FWHM 8 mm). None of the mothers had to be discarded from further analysis due to head movements (all scan-by-scan movements ≤ 3 mm in *x*, *y*, and *z* directions). Subsequently, a design matrix was constructed for each mother by modeling the onset of the face presentation (convolved with the canonical hemodynamic response function) as separate regressors for the six combinations of facial affect (happy, sad, neutral) and familiarity of the child (own, unknown), as well as six regressors for movement parameters. Finally, fMRI time series were high-pass filtered (cutoff 120 s) and temporal autocorrelation was modeled as a first-order autoregressive process.

Consistent effects across participants and between groups were assessed in a random effects multiple regression analysis with 12 contrast images (happy—own child, happy—unknown child, sad—own child, sad—unknown child, neutral—own child, neutral—unknown child for each group, respectively), which represented the estimated effects of the three experimental factors: group (ELM, CON), facial emotion (happy, sad, neutral), and familiarity of the child (own, unknown). Lifetime diagnoses of mental disorders were included as covariate of no interest.

To address our research questions, we first focused on the own child. Analyses assessed effects of facial emotion, reflecting differences in happy vs. neutral and sad vs. neutral faces. Since our previous study revealed ELM-related differences in the processing of positive or pleasant interpersonal stimuli [25], we were primarily interested in

the processing of facial happiness. We therefore first tested for general effects of facial happiness by performing an analysis of happy > neutral expressions of the own child across groups and for each group separately. In a second step, the same analyses were performed for facial sadness. Finally, we assessed whether the effects were specific for the own child by contrasting own vs. unknown child faces across both groups and for each group separately.

We used a hypothesis-driven region-of-interest (ROI) analysis as well as exploratory whole-brain analyses. Therefore, two ROIs were created based on the results of Kluczniok et al. [24], who have identified a network of brain regions involved in the processing of one's own child's happy and sad facial emotions using the same paradigm. For facial happiness, the ROI included the bilateral superior temporal, the inferior parietal, and the middle temporal gyri, the cuneus, the insula, the hippocampus, and the parahippocampal gyri. For facial sadness, the ROI comprised the superior frontal, middle orbitofrontal, precentral, superior temporal, and middle temporal gyri, the anterior and the posterior cingulate gyri, the putamen, the insula, the amygdala, the hippocampus, and the parahippocampal gyri (see [24] for details; and WFU Pick Atlas for anatomic ROI definition). We assessed the effects of facial emotion within one group and tested whether those effects were specific to that group and thus significantly weaker in the other group. This was done by applying a strict family-wise error (FWE) voxel-level correction for multiple comparisons ($p_{FWE} < 0.05$ based on recent recommendations [31]) on the effect of interest (group-specific effect of facial affect) and masking that contrast with the group \times facial emotion contrast (at $p < 0.05$ uncorrected; also see [32, 33]). For the analyses contrasting own vs. unknown child faces, whole-brain analyses with an FWE correction for multiple comparisons ($p_{FWE} < 0.05$) were used.

Results

Behavioral data

Mean reaction times and error rates for each group as well as standard deviations are presented in Table 2. We did not find any group differences in reaction times or error rates in the classification of happy, sad, or neutral facial emotions of the mother's own or an unknown child (insignificant main effect of group (all $F(1,45) < 1.0$; $p > 0.05$; $\eta_p^2 < 0.20$) as well as insignificant group by facial affect and familiarity interactions (all $F < 3.0$; $p > .05$; $\eta_p^2 < 0.20$)). Significant main effects of facial emotion revealed generally faster ($F(2,86) = 114.563$, $p < 0.001$, $= 0.73$) and more correct ($F(2,88) = 34.087$, $p < 0.001$, $= 0.44$) responses for happy than sad and neutral faces. A significant interaction of facial emotion by familiarity ($F(2,86) = 3.811$, $p < 0.05$, $= 0.08$) was found indicating faster responses for sad faces of the unknown child and for happy faces of the mother's own child.

Mean arousal and valence ratings from the picture-rating task are also shown in Table 2. Happy faces were rated as more positive and sad faces as more negative than neutral faces, and happy and sad faces received higher arousal ratings than neutral faces; also, faces of the mother's own child were rated as more positive and arousing than faces of the unknown child (all $F(2,41) > 18.0$; $p < 0.001$; > 0.30). No significant group differences were found in arousal and valence ratings (all $F(1,42) < 3.0$; $p > 0.05$; < 0.10).

FMRI data

Happy vs. neutral faces: own child

The multiple regression analysis revealed a significant facial happiness effect (contrast happy > neutral expressions of

Table 2 Behavioral data

Condition	Response times (ms)		Error rates (%)		Arousal (7-point scale)		Valence (7-point scale)	
	ELM ($N=26$) M \pm SD	CON ($N=20$) M \pm SD	ELM ($N=26$) M \pm SD	CON ($N=20$) M \pm SD	ELM ($N=24$) M \pm SD	CON ($N=20$) M \pm SD	ELM ($N=24$) M \pm SD	CON ($N=20$) M \pm SD
Happy—own	820.7 \pm 107.8	793.2 \pm 92.9	0.8 \pm 1.4	0.6 \pm 1.4	5.1 \pm 1.7	5.8 \pm 1.0	6.6 \pm 0.4	6.6 \pm 0.5
Sad—own	1184.4 \pm 238.3	1194.6 \pm 226.9	23.3 \pm 21.1	26.0 \pm 26.1	4.6 \pm 1.1	3.6 \pm 1.0	2.8 \pm 0.9	3.0 \pm 0.8
Neutral—own	1203.1 \pm 208.5	1128.5 \pm 159.1	23.2 \pm 18.3	9.8 \pm 9.3	4.0 \pm 0.9	4.1 \pm 0.7	4.1 \pm 0.7	4.3 \pm 0.7
Happy—unknown	865.2 \pm 108.7	833.7 \pm 88.5	1.0 \pm 2.3	1.9 \pm 3.7	4.3 \pm 1.3	4.7 \pm 1.0	5.8 \pm 0.6	6.0 \pm 0.5
Sad—unknown	1113.1 \pm 203.4	1149.1 \pm 238.5	18.3 \pm 24.6	18.0 \pm 22.6	4.1 \pm 1.0	4.0 \pm 1.0	2.9 \pm 0.7	3.1 \pm 0.5
Neutral—unknown	1154.0 \pm 174.7	1194.0 \pm 180.2	16.8 \pm 13.1	19.3 \pm 14.5	3.6 \pm 1.0	3.6 \pm 1.0	4.0 \pm 0.4	4.1 \pm 0.4

ELM mothers with early life maltreatment, CON mothers without early life maltreatment, M mean, SD standard deviation

the own child) across both groups in the left cuneus, the left middle temporal gyrus (MTG), the left inferior parietal gyrus, the bilateral superior temporal gyri (STG), and the bilateral parahippocampal gyri (ROI: all $k \geq 77$, all $p_{FWE} < 0.001$; see Table 3 for significant ROI results). The whole-brain analysis additionally revealed significant activations in the middle cingulum, the left gyrus angularis, the medial orbitofrontal cortex, the left superior frontal, the right supramarginal, and the precentral gyri (all $k \geq 33$, all $p_{FWE} \leq 0.001$; see Table 3 for details). This happiness effect was driven by the ELM group in the left cuneus (ROI: peak voxel MNI $[x,y,z]$: $-3, -64, 22 = 191$, $p_{FWE} < 0.001$), the bilateral STG extending to the superior temporal sulci (STS) (ROI: right STG $[x,y,z]$: $63, -25, 16 = 476$, $p_{FWE} < 0.001$; left STG $[x,y,z]$: $-63, -34, 22$, $k = 375$, $p_{FWE} < 0.001$; see Fig. 1), the left parahippocampal gyrus (ROI: $[x,y,z]$: $-27, -40, -5$, $k = 26$, $p_{FWE} = 0.013$), the middle cingulum (whole brain: $[x,y,z]$: $-6, -40, 46$, $k = 685$, $p_{FWE} < 0.001$), the right precentral gyrus (whole brain: $[x,y,z]$: $54, -1, 7$, $k = 287$, $p_{FWE} < 0.001$), and the left MTG (whole brain: $[x,y,z]$: $-45, -70, 25$, $k = 138$, $p_{FWE} < 0.001$) and it was significantly weaker in CON mothers (as the reported results in the ELM group remained after masking the main effect in ELM mothers by the group (ELM > CON) \times happiness interaction). Additionally, ELM mothers showed significant activations in response to happy vs. neutral faces of their own child in the precuneus (whole brain: $[x,y,z]$: $0, -61, 25$, $k = 101$, $p_{FWE} < 0.001$) and the left supramarginal gyrus (whole brain: $[x,y,z]$: $-63, -34, 34$, $k = 177$, $p_{FWE} < 0.001$). Activations in these regions were significantly weaker in CON mothers as the reported results remained after masking the effect in ELM mothers by the group (ELM > CON) \times happiness interaction. In contrast to our hypothesis, we did not find reduced activity in regions of the salience network in ELM compared to CON mothers in response to happy vs. neutral faces of their own child.

Sad vs. neutral faces: own child

In the present study, the multiple regression analysis did not reveal a significant sadness effect (contrast sad > neutral expression of the own child) across both groups and no significant activations in the ELM group for sad vs. neutral expressions of the own child after masking the main group effect by the group (ELM > CON) \times sadness interaction.

Own vs. unknown child

The multiple regression analysis revealed a significant familiarity effect (contrast own > unknown child) across both groups in the posterior cingulate, the bilateral fusiform, the right inferior frontal, and the right superior frontal gyri, the left anterior insula, the right temporal pole, and

the bilateral middle temporal gyri (whole brain: all $k \geq 72$, all $p_{FWE} < 0.001$; see Table 3 for details). In the bilateral inferior frontal gyri (whole brain: $[x,y,z]$: $51, 32, 10$, $k = 403$, $p_{FWE} < 0.001$ and $30, 29, -11$, $k = 21$, $p_{FWE} < 0.001$) and the bilateral fusiform gyri (whole brain: $[x,y,z]$: $42, -58, -11$, $k = 89$, $p_{FWE} < 0.001$ and $-42, -70, -11$, $k = 26$, $p_{FWE} = 0.001$), this effect was driven by the ELM group and it was significantly weaker in CON mothers (as the reported result in ELM mothers remained after masking the main effect in ELM mothers by group (ELM > CON) \times familiarity interaction thresholded at $p < 0.05$; see Fig. 2). On the other hand, CON mothers showed a significant familiarity effect in the medial frontal gyrus (whole brain: $[x,y,z]$: $-6, 50, -5$, $k = 63$, $p_{FWE} < 0.001$), which was significantly weaker in the ELM group (as the result in the CON group remained after masking the main effect in CON mothers by group (CON > ELM) \times familiarity interaction thresholded at $p < 0.05$).

Discussion

This study investigated the effects of ELM on mothers' processing of positive and negative facial emotions of their own child using functional magnetic resonance imaging. We found a happiness effect showing heightened maternal responsiveness to happy vs. neutral faces of the own child in the face perception and emotion processing networks (e.g., cuneus, MTG, STG, parahippocampal gyri). Importantly, mothers with ELM showed stronger activations in the STG, the inferior parietal lobule, the precuneus, the cuneus, the parahippocampal gyrus, and the precentral gyrus than control mothers without ELM, indicating an impact of ELM on the processing of happy faces of the mother's own child. Additionally, we found an effect of familiarity (own vs. unknown child) in the face perception network that was driven by the ELM group in the fusiform and the inferior frontal gyri, underlining the specificity of the findings for the own child.

The finding of increased neural activation in the face perception and the emotion processing networks in response to happy vs. neutral faces of the mother's own child is in line with previous research on emotional face recognition [17]. Our ROI analysis especially confirms a study using a similar paradigm in healthy mothers [24]. Most interestingly, activations found in mothers with ELM that were significantly weaker in CON mothers indicate an altered processing of child facial emotions after experiences of ELM. Consistent with our hypothesis, we found enhanced activity in ELM mothers in response to happy vs. neutral faces of their own child in the STG and the precuneus, two core regions of the mentalizing network [34–36]. In line with this, we found enhanced activity in ELM mothers in the inferior parietal

Table 3 FMRI data

Contrast	Cluster size k	T	p_{FWE}	Peak voxel MNI: x, y, z (mm)	Anatomical location of peak voxel
Happy—own > neutral—own					
ROI analysis	509	7.99	<0.001	−3, −64, 22	Cuneus
	369	7.61	<0.001	−60, −1, −14	Middle temporal gyrus
	77	7.11	<0.001	−60, −37, 40	Inferior parietal gyrus
	935	6.65	<0.001	66, −10, −11	Superior temporal gyrus
	290	6.38	<0.001	−27, −28, −14	Parahippocampal gyrus
	265	6.20	<0.001	27, −25, −17	Parahippocampal gyrus
	199	6.10	<0.001	−63, −34, 22	Superior temporal gyrus
Whole-brain analysis	1545	9.66	<0.001	−6, −40, 46	Middle cingulum
	509	8.80	<0.001	−45, −73, 28	Gyrus angularis
	597	8.55	<0.001	−3, 47, −5	Medial orbitofrontal cortex
	184	8.29	<0.001	63, −4, −17	Middle temporal gyrus
	249	7.99	<0.001	−63, −10, −14	Middle temporal gyrus
	162	7.44	<0.001	−66, −34, 31	Inferior parietal lobule
	127	7.21	<0.001	57, 2, 7	Precentral gyrus
	131	6.85	<0.001	−21, 23, 40	Superior frontal gyrus
	248	6.41	<0.001	60, −31, 34	Supramarginal gyrus
	158	6.38	<0.001	−27, −28, −14	Parahippocampal gyrus
	41	6.20	<0.001	27, −25, −17	Parahippocampal gyrus
	33	5.88	<0.001	−33, −16, 34	Precentral gyrus
	60	5.71	0.001	48, −13, 40	Precentral gyrus
	55	5.54	0.001	54, −61, 22	Middle temporal gyrus
ELM: happy—own > neutral—own masked with group × (happy—own > neutral—own)					
ROI analysis	191	7.58	<0.001	−3, −64, 22	Cuneus
	476	6.73	<0.001	63, −25, 16	Superior temporal gyrus
	375	6.56	<0.001	−63, −34, 22	Superior temporal gyrus
	26	4.53	0.013	−27, −40, −5	Parahippocampal gyrus
	25	4.42	0.021	18, −79, 40	Cuneus
Whole-brain analysis	685	8.79	<0.001	−6, −40, 46	Middle cingulum
	101	8.47	<0.001	0, −61, 25	Precuneus
	177	7.35	<0.001	−63, −34, 34	Supramarginal gyrus
	287	7.15	<0.001	54, −1, 7	Precentral gyrus
	138	6.85	<0.001	−45, −70, 25	Middle temporal gyrus
	253	6.73	<0.001	63, −25, 16	Superior temporal gyrus
	93	6.23	<0.001	−57, −1, 1	Superior temporal gyrus
Contrast	Cluster size k	T	p_{FWE}	Peak voxel MNI: x, y, z (mm)	Anatomical location of peak voxel
Own > unknown					
Whole-brain analysis	337	10.39	<0.001	−6, −49, 28	Posterior cingulum
	249	9.0	<0.001	42, −46, −20	Fusiform gyrus
	654	8.37	<0.001	54, 35, 10	Inferior frontal gyrus
	725	7.84	<0.001	9, 53, 28	Superior frontal gyrus
	430	7.84	<0.001	−27, 14, −17	anterior insula
	72	7.03	<0.001	48, 14, −32	Temporal pole
	84	6.98	<0.001	−39, −49, −17	Fusiform gyrus
	93	6.79	<0.001	−57, −13, −14	Middle temporal gyrus
	152	6.54	<0.001	−45, −58, 22	Middle temporal gyrus
	102	5.81	<0.001	60, −58, 10	Middle temporal gyrus

Table 3 (continued)

Contrast	Cluster size k	T	p_{FWE}	Peak voxel MNI: x, y, z (mm)	Anatomical location of peak voxel
ELM: own > unknown masked with group \times (own > unknown)					
Whole-brain analysis	403	7.67	<0.001	51, 32, 10	Inferior frontal gyrus
	89	7.38	<0.001	42, -58, -11	Fusiform gyrus
	21	6.39	<0.001	30, 29, -11	Inferior frontal gyrus
	26	5.63	0.001	-42, -70, -11	Fusiform gyrus
CON: own > unknown masked with group \times (own > unknown)					
Whole-brain analysis	63	6.19	<0.001	-6, 50, -5	Medial frontal gyrus

ELM mothers with early life maltreatment, *CON* mothers without early life maltreatment, *M* mean, *SD* standard deviation, *MNI* Montreal Neurological Institute

Fig. 1 Activation maps for the contrast [ELM: happy—own > neutral—own masked with group \times (happy—own > neutral—own)] are overlaid on a standard MRI template; bar plots represent contrast estimates (adjusted units), data are extracted from a 3 mm sphere around the peak voxel, error bars represent the standard error of the mean; *STG* superior temporal gyrus, *ELM* mothers with early life maltreatment, *CON* mothers without early life maltreatment

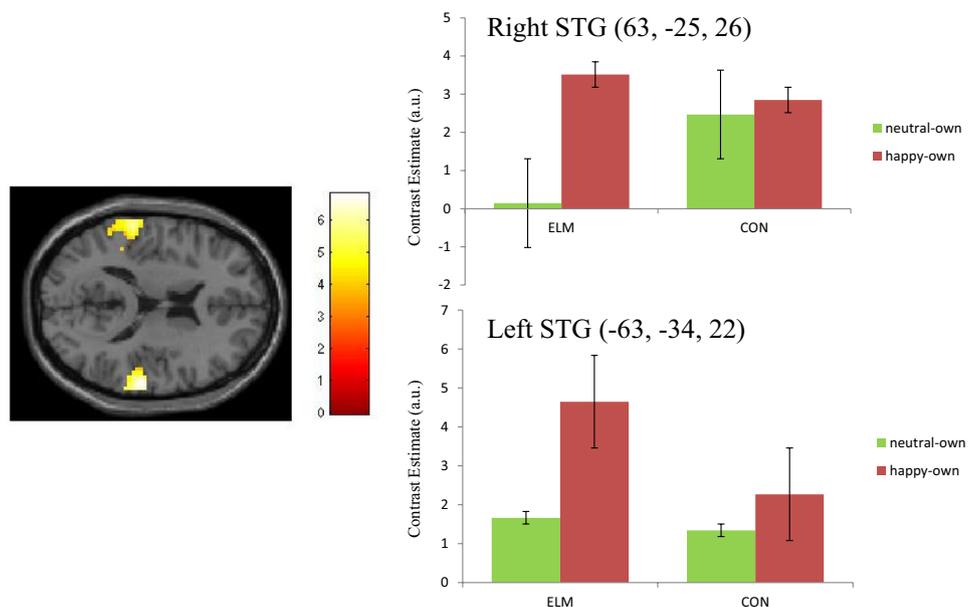
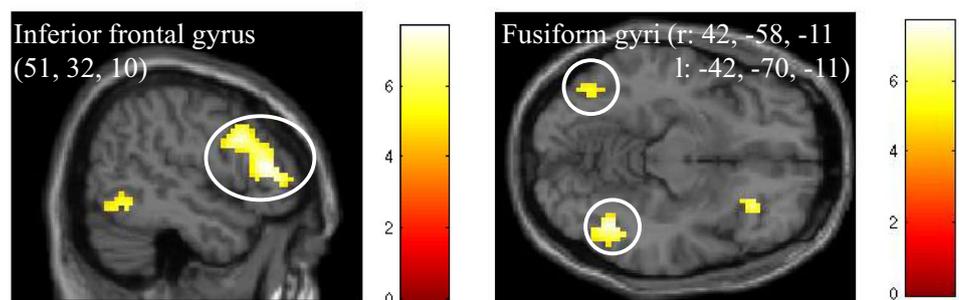


Fig. 2 Activation maps for the contrast [ELM: own > unknown masked with group \times (own > unknown)] are overlaid on a standard MRI template; *r* right, *l* left



lobule (supramarginal gyrus), which is part of the mirror neuron network [37, 38]. The mirror neuron network plays an important role in the recognition of others' intentions and, thus, supports mentalizing by representing another person's action [39]. Taken together, the activation pattern in these regions exhibited by mothers with a history of ELM, but not by non-maltreated mothers, indicates a recruitment

of mentalizing capabilities when processing happy facial emotions of their own child. This is in line with previous findings of our group showing an association of GMV of regions of the mentalizing network and maternal sensitivity in mothers with ELM, suggesting a recruitment of cognitive empathic capabilities to maintain high sensitivity [14] and with findings showing an association between positive

caregiving and precuneus activation in response to positive faces in mothers with low depressive symptoms [40]. Furthermore, patients with ELM and a current diagnosis of posttraumatic stress disorder (PTSD) were found to show impaired affective empathic capabilities [41]. Cognitive in comparison to affective empathic capabilities in parenting do not rely on sympathizing with the child's emotions, but rather imply cognitively mentalizing the child's needs which is reflected in the present findings of activations of regions of the mentalizing and mirror neuron networks. Thus, it seems that mothers with ELM do not show an empathically sympathizing response to their children's happy facial emotion, but rather apply cognitive mentalizing. Future research should examine whether this might compensate for difficulties in affectively sympathizing with the own child and thus enable mothers with ELM to sensitively respond to their child despite a lack of affective responding.

Additionally, ELM mothers show enhanced activity in response to happy vs. neutral faces of their own child in the bilateral cuneus, the left middle temporal, the left parahippocampal, and the precentral gyri. Enhanced activation of the cuneus could indicate more effortful primary visual processing of the child's face along with more effortful facial emotion processing as reflected in middle temporal gyrus activation [17]. Moreover, hyper-activation of the parahippocampal gyrus in response to happy facial emotions of the own child hints at an increased emotional contextual processing in ELM as opposed to CON mothers [42]. Besides, gray matter increase has been shown in the precentral gyrus in mothers in the first 4 months postpartum [43], suggesting an importance of this structure in the maternal brain and especially for maternal motor behavior. Taken together, these findings argue for ELM mothers having to put more effort into the processing of their children's emotions and to behaviorally respond to them. However, in contrast to our hypothesis based on the finding of lower activity in the salience network while processing complex positive interactions with one's child [25], we did not find lower activity of the brain salience network in response to happy facial emotions, which could be due to the differences in complexity and the required personal involvement of the two tasks (imagination of mother-child interaction vs. classification of facial emotions).

While the present results indicate an altered processing of the own child's happy face in ELM mothers on a neural level, we did not find a significantly different performance compared to CON mothers as expressed in reaction times or error rates. This is not surprising since the task was designed to study neural reactions (by showing facial emotions for as much as 2 s) and not to assess behavioral performance in classifying facial emotions.

We did not find a significant effect of sad vs. neutral facial emotions of the own child on either the behavioral

or neural level across groups and in each group separately. While mothers classify happy faces faster and more correctly than sad and neutral faces, there is no difference in reaction times and error rates between sad and neutral faces. Hence in this implication of the paradigm, sad faces seem to be less salient and do not elicit neural reactions as strong as happy faces in contrast to neutral faces.

Importantly, the specificity of the current findings for facial emotions of the own child is underlined by the familiarity effect we find when contrasting pictures of the own with pictures of an unknown child. Especially in the fusiform and the inferior frontal gyri, the familiarity effect was mainly driven by the ELM mothers who activate the face processing and mirror neuron networks in response to their own child stronger than control mothers.

Since it has been shown that mental disorders like depression and PTSD impact on maternal neural response to the own child [44, 45] and lifetime history of mental disorders could have exerted an influence on brain functioning in the current study, lifetime psychiatric diagnoses were included as a regressor of no interest (i.e., control factor) in the fMRI analyses, underlining the specificity of the observed neural changes for ELM.

Despite the study's strengths such as including mothers with school-aged children (an age range that has rarely been investigated before in the context of maternal facial emotion recognition) divided into a group of women with ELM and a well-matched control group of healthy mothers without ELM as well as applying an emotional face recognition paradigm showing pictures of the own child's facial emotions, findings should be considered in the light of some limitations. ELM was defined as sexual and/or physical abuse before age 18 years based on an extensive retrospective interview. Nevertheless, the sample size does not allow a finer differentiation of different age groups at onset of ELM or other maltreatment types such as emotional abuse or neglect, which have also been shown to have neurobiological impacts.

Conclusively, with regard to the processing of facial emotions of the own child as a prerequisite to sensitive maternal behavior, our results show an ELM-associated altered neural processing. In detail, the present results indicate more effort when processing facial emotions of the own child and a cognitive empathic processing and mentalizing of the own child's happy face in ELM mothers that might be important to maintain maternal sensitivity.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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