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EEG recording during an emotional face-matching task in children of mothers with interpersonal violence-related posttraumatic stress disorder

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ABSTRACT

The aim of this study was to examine the effects of maternal interpersonal violence-related posttraumatic disorder (IPV-PTSD) on child appraisal of emotion, as measured by high-density electroencephalography (HD-EEG) during an Emotional Face-matching Task (EFMT). We recorded HD-EEG in 47 children of mothers with and without IPV-PTSD during an Emotional Face-matching Task (EFMT). Mothers and children each performed the EFMT. Behavioral results demonstrated that both mothers who were directly exposed to violent events, and their children, presented attentional bias toward negative emotions when processing facial stimuli. EEG findings confirmed differences in emotion appraisal between children of IPV-PTSD mothers and non-PTSD controls at scalp-level and in terms of source localization upon which children of IPV-PTSD mothers demonstrated decreased activation of the right dorsolateral prefrontal cortex (dlPFC) in response to angry and fearful faces as compared to non-PTSD children with respect to the N170 component. Our study, to our knowledge, is the first to show that maternal IPV-PTSD significantly affects a mother's own and her child's neural activity in response to facial expressions of negative emotion. These findings are potentially important to the development and study of effective interventions to interrupt intergenerational cycles of violence and trauma.

1. Introduction

Self-regulation of emotion ("self-ER") is defined as the ability to modulate one's emotional arousal to allow adequate engagement with the environment and to permit learning (Cicchetti et al., 1991; Supplee et al., 2011). Self-ER involves inter-coordination of emotional (affective) and cognitive systems and develops over the first (Cicchetti et al., 1995). Prior to ages 4–5 years, these two systems are the least inter-coordinated; and thus the child depends on environmental support for the acquisition of self-ER, namely the parent-child relationship and the mutual parent-child ER that this relationship affords (Feldman et al., 1999; Sander, 1977). Moreover, exposure to a hostile environment (i.e. adversity, trauma, early life stress, maltreatment) can lead to changes in the appraisal of emotion, in order to enhance the emotional information processing of salient or threat-related stimuli (i.e. associated with negative emotions such as fear/helplessness and anger/hostility) (Marusak et al., 2015).

Studies suggest that maternal interpersonal violence-related posttraumatic stress disorder (IPV-PTSD) can compromise maternal self-ER and, by extension, mutual parent-child ER (Pat-Horenczyk et al., 2015; Schechter et al., 2010). Maternal IPV-PTSD can do so through the combined effect of its inherent re-experiencing, avoidance, and hyperarousal symptoms. We assert that a traumatized parent can be triggered into a sympathetic nervous system-driven, hyperaroused state by her own toddler's helpless distress, even during normative day-to-day interactions (Schechter et al., 2014). Studies have furthermore shown

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that when traumatized mothers experience this type of self-dysregulation, they more likely misattribute their child's mental states and misappraise their child's emotional expression (Lieberman, 1997; Schechter et al., 2006; Schechter et al., 2015).

Processing faces and being able to differentiate emotional expressions is one component of self-ER. Very young children need to develop their own capacities to appraise and react appropriately to others' emotional communication in the context of the parent-child relationship—typically, the mother-child relationship. This being the case, we expect that children exposed to maternal caregiving that is filtered through the lens of maternal IPV-PTSD and that is thus likely less regulated and regulating -and thus less sensitive, will have more difficulty with emotion appraisal. These children's own emotions are often not correctly identified by their primary caregiver with any consistency (Schechter et al., 2008; Schechter et al., 2015).

High-density electroencephalography (HD-EEG) can be used to examine early stages of brain activation during face processing and emotion appraisal. Investigators usually identify three specific event-related potential (ERP) components, occurring early in time after visual stimuli presentation (Berchio et al., 2017; Schwab and Schienle, 2017):

1) P100: an early visual component appearing around 120 ms after stimulus presentation in children, generated in the primary cortex and associated with posterior positive deflection, that has been described as corresponding to attentional processing of faces (Schwab and Schienle, 2017);
2) N170: a component appearing around 190 ms after stimulus onset in children, N170 is a specific negative deflection known to reflect structural encoding of faces (Curtis and Cicchetti, 2011), and is measured in the occipito-temporal sulcus (in the fusiform gyrus). For non-facial stimuli (i.e. geometric shapes), the negative potential is measured over occipital electrodes and the component is usually named N200;
3) Late Positive Potential (LPP): appears between 300 and 500 ms after stimulus presentation and corresponds to higher levels of cognitive processing such as attention-driven functions (i.e. bottom-up and top-down processes) and to the amount of attentional resources allocated to the stimulus. Brain sources of the LPP are mainly located in prefrontal regions.

In the present study, we considered a sample of mothers exposed to interpersonal violence with related posttraumatic disorder (IPV-PTSD), non-PTSD mothers, and their young children at ages 5–9 years. This paper represents a longitudinal follow-up study of the same mothers and children who participated earlier in the Geneva Early Childhood Stress Project, “Phase 1,” when the children were 12–42 months of age (GECS-Pro, see Moser et al., 2015; Schechter et al., 2017). We expected that the aforementioned disturbances related to maternal psychopathology noted in Phase 1 of this study would lead to difficulties in emotion processing in their children at school-age (5–9 years) (“Phase 2”).

1.1. Our a-priori hypotheses

Maternal IPV-PTSD diagnosis as well as IPV-PTSD and maternal dissociative symptom severity will be associated with the following:

1) Difficulties in identifying emotions both among IPV-PTSD afflicted mothers and their children, with particular errors noted for the appraisal of negative emotions (i.e. anger and fear) and a possible attentional bias to these emotions;
2) Altered emotional processing and corresponding increased amplitudes of the P1 and N170 components (i.e. greater reactivity) in response to negative emotions among children of IPV-PTSD mothers compared to non-PTSD controls;
3) Decreased activity in brain regions known to play an important role in emotion appraisal and regulation, among children of IPV-PTSD mothers compared to those of non-PTSD controls: namely, the dorsolateral and medial prefrontal cortex (VanTieghem and Tottenham, 2017), particularly in response to negative emotions.

To our knowledge, no published studies have yet described the effects of maternal IPV-PTSD on child emotion processing using EEG-neuroimaging methods.

2. Methods

2.1. Participants

The institutional ethics committee of the Geneva University Hospitals and Faculty of Medicine approved this research project in accordance with the Helsinki Declaration (World Medical Association, 1999). Mothers and their children were included in Geneva Early Childhood Stress Project (GECS-Pro) Phase 2 if children were ages 5–9 years and had participated in Phase 1. Subjects were excluded if mothers were active substance-abusers, suffered from a psychotic disorder, or if mothers or children were physically and/or mentally impaired to participate in laboratory tasks.

For this Phase 2 study, 47 mothers and children participated following informed consent. Twenty-six children were toddlers of mothers with IPV-PTSD (mean age = 7.49 years, SD = 1.13) and 21 children were toddlers of non-PTSD mothers (mean age = 7.64, SD = 0.95). EEG was recorded in children only ($N = 47$) and behavioral data were collected in both mothers and children (47 dyads). We changed the EEG protocol after evaluation of the first seven participants, from fixed to random duration of the fixation cross presentation. These first participants ($n = 7$) were thus excluded. We also excluded subjects with poor quality data ($n = 8$). Thirty-two participants (16 children of IPV-PTSD mothers and 16 children of non-PTSD controls) were included in the final EEG analysis. No children suffered from traumatic brain injury or neurological disorders.

2.2. Clinical assessment

Children and mothers came for two 3-h visits on separate days. During both visits, clinicians interviewed mothers and children to update Phase 1 data related to life-events. Maternal IPV-PTSD diagnosis and symptom severity as well as comorbid depressive symptom severity had been assessed during Phase 1 of the GECS-Pro (see Schechter et al., (2017) for more details). We were particularly interested in how maternal IPV-PTSD and associated effects on caregiving behavior measured during Phase 1 when children were ages 12–42 months subsequently impacts child emotion appraisal at school-age (i.e. ages 5–9 years). During Phase 1 of the project, two groups had been identified according to the Clinician Administrated PTSD Scale (CAPS) and the Posttraumatic Symptom Checklist— Short Version (PCL-S): an IPV-PTSD clinical group and a non-PTSD control group. The former included all mothers who met full DSM-IV criteria for PTSD as well as subthreshold subjects who had clinically significant distress and/or impairment but fell short of the threshold for diagnosis by one or two symptoms. The CAPS and PCL-S were applied using the version compatible with the DSM-IV-TR (DSM–IV–TR; American Psychiatric Association, 2000).

In our sample, 19 children were toddlers of mothers who met criteria for DSM-IV-TR PTSD diagnosis and 7 children were toddlers of mothers who demonstrated clinically significant symptoms (PCLS score >25 and CAPS score >35) that were below the threshold for full-diagnosis. All of these children of mothers with IPV-PTSD were included in the same group, regardless of whether maternal IPV-related trauma was due principally to domestic violence (i.e. to physical and/or sexual violence with partner) alone or with accompanying history of childhood maltreatment and/or family violence exposure.

Table 1
Characteristics of IPV-PTSD and non-PTSD mothers and their children

		All	Controls (n = 21)	IPV-PTSD (n = 26)	p-value
Maternal variables	Age of the mothers (in years)	39.21 (6.18)	41.06 (6.34)	37.71 (5.77)	0.098+
	Socio-economic status (higher score means lower status)[a]	**4.98 (2.16)**	**4.22 (1.96)**	**5.57 (2.17)**	**.047**[*]
	% history of prior drug & alcohol use[a]	9.3% (4/43)	0% (0/18)	15.38% (4/26)	0.071+
	Depression (BDI)[a]	**8.93 (7.41)**	**3.94 (3.06)**	**12.52 (7.57)**	**.000**[***]
	CAPS total score[a]	**53.00 (34.73)**	**21.23 (12.19)**	**80.96 (21.02)**	**.000**[***]
	Dissociation symptoms[a]	**4.64 (6.91)**	**0.74 (1.94)**	**7.87 (7.87)**	**.000**[***]
		All	Controls (n = 21)	IPV-PTSD (n = 26)	p-value
Child variables	Age of children (in years)	7.55 (1.04)	7.64 (0.95)	7.49 (1.13)	0.647
	% boys	55.3% (26/47)	47.62% (10/21)	61.54% (16/26)	0.466
	% left-handed children	4.3% (2/47)	0% (0/21)	7.69% (2/26)	0.662

% (n/number of valid data) and mean (SD) are reported.
[a] There was three missing values within the control group.
[*] $p < .05$.
[***] $p < .001$.

During Phase 1 of the GECS-Pro, maternal depression was assessed using the Beck Depression Inventory II (BDI-II; Beck and Steer, 1987). Major depressive disorder (MDD) is frequently comorbid with IPV-PTSD in as many as 40–50% of cases (Flory and Yehuda, 2015). Family socio-economic status (SES) was calculated using the Largo Index (Largo et al., 1989) at Phase 1, when mothers were interviewed using the Geneva Sociodemographic Questionnaire (GSQ) (Sancho Rossignol et al., 2010). Following the primary analysis, we then also controlled for both SES and maternal history of depression (using the BDI) in our analyses. The two groups were matched in laterality, gender and ages. Demographical and clinical characteristics are presented in Table 1.

2.3. Behavioral task

During the second visit, mothers and children performed an Emotional Face-matching Task (EFMT; Hariri et al., 2002). During the EFMT, three faces are presented in a triangular arrangement. Participants select one of the two faces at the bottom sharing the same emotion than the one at the top. Emotions presented are angry, fearful and happy faces. The paradigm was adapted for recording ERPs. We first presented the emotional face in the center of the screen (22.5 cm × 21 cm). The emotional face was followed by a triangular arrangement, where the emotional cue took place at the top of the screen and the two faces to match appeared at the bottom. Faces were presented for 600 ms on a white background, preceded by a fixation cross (randomly varied between 905 and 1135 ms) and followed by the matching part (4 s). Stimuli were taken from the NimStim set of facial expressions (Tottenham et al., 2009) (Fig. 1).

Visual stimuli were distributed into six blocks, each composed of 72 stimuli (16 angry faces, 16 fearful faces, 16 happy faces, 16 shapes and 8 cartoon pictures used as entertainment). Half of the faces depicted male actors and half depicted female actors. A neutral face comparison condition was not shown given that at least one study demonstrated that clinical populations tend to perceive neutral faces as expressive of negative emotion, with a bias towards anger (Marusak et al., 2016). Geometric shapes were shown as a control condition in a parallel matching task. Participants matched the faces or shapes using a multifunctional response console (chrono; PSYCHOLOGY SOFTWARE TOOLS, INC.).

2.4. EEG data acquisition and pre-processing

EEG data were acquired with a 256-channel Electrical Geodesic Inc. System (Eugene, OR), and a sampling rate of 1000 Hz, and Cz as acquisition reference. Electrodes impedances were kept below 30 KOhm. Offline analyses were performed using Cartool 3.60 (4698) Software (https://sites.google.com/site/cartoolcommunity). EEG epochs were segmented 100 ms before and 600 ms after stimulus onsets and were digitally filtered offline at 0.1–40 Hz (causal filter, 24 db/octave roll-off) and a notch filter was applied. Electrodes at neck and jaw were excluded, leaving 204 electrodes analyzed. The EEG was visually inspected and epochs containing artifacts were excluded from further analysis. Artefactual electrodes were interpolated using spherical spline interpolation method (Perrin et al., 1989) implemented in the Cartool software. ERP data were recalculated against the average reference.

2.5. Analysis of behavioral data

After exploratory analysis using box-plots or scatter-plots to detect outliers for each analysis, Mann Whitney U tests were used to compare IPV-PTSD and non-PTSD groups for accuracy, context of errors[2] and reaction (RT) of the EFMT. Continuous analyses were performed using Spearman's rank correlation coefficients and a resampling-based false discovery rate (FDR) adjustment was applied to correct for multiple comparisons (Yekutieli and Benjamini, 1999). Following the initial analysis, we controlled for both maternal depression and SES by entering any significant associations into a linear regression model. Statistics were computed using SPSS version 22 (IBM Corporation, Armonk, NY, USA). All tests were two-tailed, with significance level at 0.05.

2.6. ERP analyses

We analyzed child responses to emotional faces and shapes using global scalp analysis and EEG source imaging methods (for details see Berchio et al., 2017; Brunet et al., 2011; Michel and Murray, 2012; Murray et al., 2008; Murray et al., 2009).

2.6.1. ERPs to faces

Differences in ERPs topographies between emotions and shapes in all participants together were investigated with a non-parametric test called “topographical ANOVA” or “TANOVA” (see Koenig et al., 2011; Michel and Murray, 2012). We used 1000 permutations with a threshold of $p < 0.01$ and a time constraint of ≥16 ms of successive significant tests.

ERP strength in response to emotional faces was evaluated using Global Field Power (GFP), which corresponds to a global index of synchronization of the neuronal activity that is measured using the sum of the squared potential differences in all electrodes recorded (Skrandies, 1990). GFP differences were investigated using a 3 × 2 design with randomization tests (Koenig et al., 2011), with Facial Expressions of Emotions (i.e. anger, fear and happiness) as within-subject

[2] Context of errors corresponds to the matching context, thus the emotional contents of the two faces presented in opposition at the bottom of the screen (i.e. fearful or happy stimulus instead of angry face).

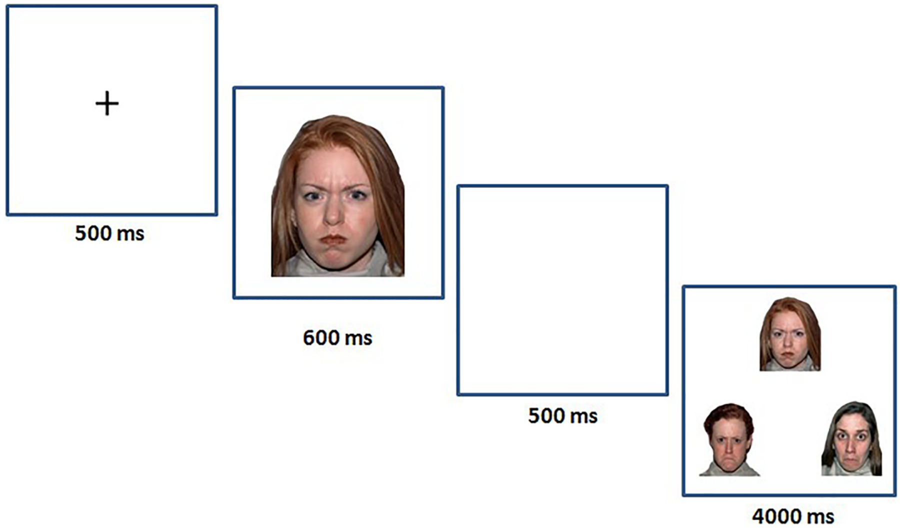

Fig. 1. Emotional Face-matching Task EEG-adapted, using NimStim stimuli.

Table 2
Mann Whitney *U* test on Emotional Face-matching Task (EFMT) to consider group differences.

2A: maternal EFMT:

Errors	Angry faces Errors	Angry faces RT	Fearful faces Errors	Fearful faces RT	Happy faces Erorrs	Happy faces RT	Shapes Errors	Shapes RT
N	45	46	43	46	43	45	43	44
Mann-Whitney U	181.000	243.000	138.000	256.000	194.000	235.000	108.000	207.000
Wilcoxon W	371.000	453.000	309.000	466.000	384.000	560.000	279.000	532.000
Z	−1.519	−0.377	−2.147	−0.089	−0.836	−0.343	−3.549	−0.723
Asymp. Sig (2-tailed)	0.129	0.706	**0.032***	0.929	0.403	0.732	**0.002**	0.470

Confusion	Cue Angry	Selection Fearful	Cue Angry	Selection Happy	Cue Fearful	Selection Angry	Cue Fearful	Selection Happy	Cue Happy	Selection Angry	Cue Happy	Selection Fearful
N	46		43		45		39		46		45	
Mann-Whitney U	222.500		202.000		205.500		116.500		228.500		172.500	
Wilcoxon W	432.500		392.000		415.500		269.500		438.500		362.500	
Z	−0.834		−0.656		−1.020		−2.053		−0.737		−1.770	
Asymp. Sig (2-tailed)	0.404		0.512		0.308		**0.040***		0.461		0.077	

2B: child EFMT:

Errors	Angry faces Errors	Angry faces RT	Fearful faces Errors	Fearful faces RT	Happy faces Errors	Happy faces RT	Shapes Errors	Shapes RT
N	46	47	46	47	43	47	39	45
Mann-Whitney U	219.500	207.000	195.000	225.000	146.500	212.000	181.500	165.000
Wilcoxon W	450.500	460.000	426.000	478.000	356.500	465.000	371.500	375.000
Z	−0.950	−1.450	−1.490	−1.066	−2.035	−1.343	−0.243	−1.942
Asymp. Sig (2-tailed)	0.342	0.147	0.136	0.286	**0.042***	0.179	0.808	0.052

Confusion	Cue Angry	Selection Fearful	Cue Angry	Selection Happy	Cue Fearful	Selection Angry	Cue Fearful	Selection Happy	Cue Happy	Selection Angry	Cue Happy	Selection Fearful
N	45		44		38		44		43		44	
Mann-Whitney U	198.500		202.000		64.500		210.500		174.000		193.500	
Wilcoxon W	474.500		455.000		317.500		441.500		384.000		446.500	
Z	−1.243		−0.954		−3.328		−0.743		−1.413		−1.169	
Asymp. Sig (2-tailed)	0.214		0.340		**0.001**		0.458		0.158		0.243	

* Not significant with FDR correction for multiple comparisons.

factors and Groups (PTSD vs non-PTSD controls) as between-subject factors using RAGU software (http://www.thomaskoenig.ch/index.php/work/ragu/1-ragu). Based on visual inspection of the grand averages (GFP maximums/minimums), the analysis was performed on the time-window corresponding to the latency of the P1 (100–175 ms), N170 (176–270 ms) and LPP (271–600 ms) components, with an alpha set to $p < 0.05$ and with 5000 randomization runs. Effects were considered as statistically significant only if they lasted for at least five consecutive time frames (20 ms).

2.7. ERP source analyses

We performed analyses in the source space using a Local Auto Regressive Average (LAURA) inverse solution model (Menendez et al., 2001; Michel et al., 2001). Current density distribution was calculated for 5015 solutions points located in the grey matter of a child template head model (MNI brain: http://www.bic.mni.mcgill.ca/ServicesAtlases/MNI305). The local spherical model with anatomical constraints (LSMAC) was used for the forward solution (Birot et al., 2014; Brunet et al., 2011). The current density values were averaged across the N170 component time window (176–270 ms) and then subjected to randomization test (i.e. 5000 permutations, p-values less than 0.05). Permutation statistics were used to adjust for multiple comparisons (Maris and Oostenveld, 2007). T-values were extracted in order to know the direction of effect. More details can be found in supplementary information.

3. Results

3.1. Behavioral results

3.1.1. Associations between maternal psychopathology and maternal and child responses to the EFMT

Categorical analyses using Mann Whitney U tests of EFMT maternal behavioral data (i.e. IPV-PTSD versus non-PTSD controls), with respect to appraisal of angry, fearful and happy faces showed no significant differences after FDR correction for multiple comparisons. We only unexpectedly found significant group differences with greater difficulties in matching shapes among IPV-PTSD mothers as compared to non-PTSD controls ($U = 108.0$, $p = .002$, $N = 43$). However, categorical analyses using Mann Whitney U tests of EFMT child behavioral data showed that children of IPV-PTSD mothers, as compared to those of non-PTSD mothers, made more errors that reflected significantly increased confusion between the two negative emotions presented (i.e. fear as the cue and anger as the matched response) ($U = 64.5$, $p = .001$, $N = 38$). This result remained significant after FDR correction for multiple comparisons. Results are displayed in Table 2A (maternal EFMT) and B (child EFMT).

Continuous analyses via Spearman correlations (i.e. permitting greater statistical power) allowed us to examine associations between maternal IPV-PTSD symptoms and severity, along with related dissociative symptom severity on the CAPS during Phase 1, and maternal-child EFMT behavioral data during Phase 2. Maternal PTSD severity (CAPS overall score) was, in these analyses, significantly associated with increased maternal errors in identifying the two negative emotions presented: angry ($r = 0.317$, $p = .034$, $N = 45$) and fearful faces ($r = 0.161$, $p = .021$, $N = 43$) faces, but not happy faces. Maternal PTSD severity was also associated with errors in the identification of shapes ($r = .374$, $p = .018$, $N = 40$). Multiple linear regression was used to control for SES and depression in order to test if maternal PTSD severity would remain a predictor of maternal errors on the EFMT. Indeed, covarying SES and maternal depressive symptom severity did not significantly alter the model (all $Fs < 2.288$, all p-values $> .138$ for SES; all $Fs < 1.913$, all p-values $> .161$ for depression).

In examining the effects of PTSD symptom clusters on maternal performance on the EFMT, Spearman correlations showed that the association between maternal IPV-PTSD severity and the EFMT was mainly due to the severity of two symptom clusters, namely: 1) the avoidance cluster as associated with increased maternal errors in the appraisal of negative emotions. The latter included angry ($r = 0.310$, $p = .043$, $N = 43$) and fearful ($r = 0.396$, $p = .009$, $N = 42$), but not positive emotions (i.e. happy). And 2) the hyperarousal cluster was associated with increased maternal errors similarly in the appraisal of negative emotions. The latter included angry ($r = 0.437$, $p = .003$, $N = 43$) and fearful ($r = 0.336$, $p = .030$, $N = 42$), but not positive emotions (i.e. happy). Maternal re-experiencing symptoms were associated with increased maternal confusion between fearful and happy faces ($r > .330$, $p < .029$, $N = 44$), but did not survive FDR correction for multiple comparisons. Finally, maternal errors in the identification of shapes were associated with maternal avoidance ($r = .390$, $p = .015$, $N = 38$) and hyperarousal symptoms ($r = 0.345$, $p = .034$, $N = 38$), but also with maternal dissociative symptoms on the CAPS such as derealization and depersonalization ($r = -0.346$, $p = .042$, $N = 35$). Associations between maternal IPV-PTSD severity and maternal EFMT are summarized in Table 3A.

We further considered the effects of maternal IPV-PTSD severity and symptom clusters on child performance on the EFMT. Spearman correlations showed that the association between maternal IPV-PTSD severity and child EFMT performance was mainly due to maternal hyperarousal symptoms which was associated with increased child errors in the appraisal of fearful faces ($r = 0.354$, $p = .025$, $N = 40$). Maternal re-experiencing symptoms were also associated with better child capacities to distinguish between anger and fear ($r = -0.33$, $p = .038$, $N = 40$). However, none of those results survived FDR correction for multiple comparisons. Associations between maternal IPV-PTSD severity and child EFMT are demonstrated in Table 3B.

3.2. Evoked potential results

3.2.1. ERP analyses on the scalp level

Visual inspection of grand-mean evoked responses and corresponding GFP in response both to faces and shapes in all participants together confirmed the presence of three main ERPs components (Fig. 2): P1 (100–175 ms; max GFP amplitude at 132 ms for faces and at 136 ms for shapes), N170 (176–270 ms; max GFP amplitude at 208 ms for faces and at 228 ms for shapes) and LPP (271–600 ms; max GFP amplitude at 444 ms for faces and at 460 ms for shapes).

As predicted, topographical maps supported distinct electrical distributions over the scalp between the N170 component (whereby the presentation of faces induced a specific pattern of lateral posterior negativity) and the N200 component (whereby the presentation of shapes led to occipital negativity). These differences in response to faces and shapes with respect to ERP components N170/N200 and LPP were confirmed by the Topographical ANOVA (TANOVA) ($p < .001$, lasting between 184 and 568 ms after stimulus onset). Visual inspection and TANOVA results are displayed in Fig. 2.

ANOVA on GFP values using emotions as within-subjects factor and groups as between-subjects factor showed significant interactions between emotions and groups in two different time windows: from 120 to 156 ms (corresponding to the P1 component, $p = .019$) and from 244 to 272 ms (corresponding to the N170 component, $p = .008$) after stimulus onset. Post-hoc comparisons using unpaired t-tests demonstrated significant differences in GFP amplitude values between groups for the N170 component, with children of IPV-PTSD mothers showing greater hyperresponsivity to happy faces (mean GFP value in children of IPV-PTSD mothers = 4.34 μv, SD = 0.47; mean GFP value in non-PTSD controls = 3.05 μv, SD = 0.29). Differences were neither significant for negative emotions nor, as indicated by the P1 ERPs component, for all emotions including positive emotion. We analyzed control-trials in which shapes were the displayed stimuli and found no significant interactions (all $p > .05$). Results of the GFP analysis with respect to the N170 ERP component are shown in Fig. 3. We also controlled GFP results for maternal depressive symptom severity, since happy faces might stimulate increased recruitment due to novelty of positive emotion in the presence of a depressed caregiver. However, this was not the case.

3.3. Analysis in the source space

In response to negative emotions (i.e. angry and fearful faces), children of IPV-PTSD mothers compared to children of non-PTSD controls demonstrated decreased activity in the right dorsolateral prefrontal cortex (dlPFC) during the N170 component. Increased activity was found in the left ventromedial prefrontal cortex (vmPFC)/orbitofrontal cortex (OFC) in IPV-PTSD children as well as decreased activation in the right orbitofrontal cortex (PFC) in response to angry faces. Additional findings noted patterns of neural activity in the temporal lobe that are consistent with decreased activation in the left middle temporal gyrus (MTG) in response to angry faces, and in the right MTG in response to fearful faces. Decreased activity was found in the right superior temporal gyrus (STG) in response to fearful faces among children of IPV-PTSD mothers as compared to controls. Finally,

Table 3
Spearman's correlations between maternal psychopathology and maternal and child responses on the Emotional Face Matching Task (EFMT)

3A: maternal EFMT: **Spearman's correlations**		Angry faces Errors	Angry faces RT	Fearful faces Errors	Fearful faces RT	Happy faces Errors	Happy faces RT	Shapes Errors	Shapes RT	Cue Angry Selection Fearful	Cue Angry Selection Happy	Cue Fearful Selection Angry	Cue Fearful Selection Happy	Cue Happy Selection Angry	Cue Happy Selection Fearful
Maternal CAPS total score	r	0.317	0.161	0.351	0.113	0.209	0.12	0.374	−0.204	0.196	0.029	0.102	0.215	0.175	0.125
	p	**0.034**	0.303	**0.021**	0.456	0.172	0.439	**0.018**	0.207	0.193	0.849	0.501	0.152	0.244	0.409
	N	45	43	43	46	44	44	40	40	46	46	46	46	46	46
Maternal re-experiencing symptoms	r	0.266	0.146	0.097	0.125	0.077	0.111	0.239	−0.117	0.135	0.052	0.24	0.349	0.04	0.33
	p	0.085	0.362	0.541	0.42	0.626	0.483	0.148	0.485	0.382	0.737	0.116	**0.02***	0.796	**0.029***
	N	43	41	42	44	42	42	38	38	44	44	44	44	44	44
Maternal avoidance symptoms	r	0.31	0.166	0.396	0.15	0.301	0.155	0.39	−0.222	0.197	0.162	0.212	0.273	0.201	0.087
	p	**0.043**	0.299	**0.009**	0.333	0.053	0.328	**0.015**	0.18	0.201	0.294	0.166	0.073	0.192	0.575
	N	43	41	42	44	42	42	38	38	44	44	44	44	44	44
Maternal hyperarousal symptoms	r	0.437	0.129	0.336	0.135	0.162	0.168	0.345	−0.074	0.307	0.283	0.14	0.234	0.112	0.184
	p	**0.003**	0.42	**0.03**	0.381	0.306	0.287	**0.034**	0.659	**0.043***	0.073	0.384	0.142	0.486	0.249
	N	43	41	42	44	42	42	38	38	44	41	41	41	41	41
Maternal dissociation symptoms	r	0.105	0.115	0.314	0.021	0.237	0.066	0.084	−0.346	−0.059	0.02	0.046	0.218	0.099	0.061
	p	0.518	0.491	0.052	0.895	0.141	0.688	0.631	**0.042**	0.715	0.897	0.769	0.156	0.522	0.695
	N	40	38	39	41	40	40	35	35	41	44	44	44	44	44

3B: child EFMT: **Spearman's correlations**		Angry faces Errors	Angry faces RT	Fearful faces Errors	Fearful faces RT	Happy faces Errors	Happy faces RT	Shapes Errors	Shapes RT	Cue Angry Selection Fearful	Cue Angry Selection Happy	Cue Fearful Selection Angry	Cue Fearful Selection Happy	Cue Happy Selection Angry	Cue Happy Selection Fearful
Maternal CAPS total score	r	−0.019	0.14	0.175	0.118	0.085	0.057	−0.255	−0.029	−0.173	−0.113	−0.279	0.078	−0.001	−0.183
	p	0.906	0.377	0.263	0.45	0.589	0.714	0.103	0.854	0.261	0.464	0.067	0.616	0.996	0.235
	N	42	42	43	43	43	43	42	42	44	44	44	44	44	44
Maternal re-experiencing symptoms	r	−0.034	0.08	0.111	0.034	0.058	0.075	−0.088	−0.054	−0.167	0.003	−0.33	0.128	−0.009	−0.16
	p	0.837	0.635	0.499	0.836	0.725	0.649	0.6	0.747	0.302	0.985	**0.038***	0.431	0.955	0.323
	N	38	38	39	39	39	39	38	38	40	40	40	40	40	40
Maternal avoidance symptoms	r	−0.054	0.051	0.201	−0.049	0.105	0.064	−0.233	−0.15	−0.142	−0.04	−0.191	0.187	0.105	−0.133
	p	0.75	0.76	0.22	0.769	0.524	0.7	0.16	0.37	0.382	0.805	0.237	0.249	0.518	0.415
	N	38	38	39	39	39	39	38	38	40	40	40	40	40	40
Maternal hyperarousal symptoms	r	0.126	0.273	0.354	0.224	0.169	0.1	−0.022	0.187	0.188	−0.012	0.038	0.211	0.238	0.137
	p	0.451	0.098	**0.025***	0.165	0.297	0.538	0.895	0.262	0.246	0.943	0.815	0.19	0.139	0.4
	N	38	38	40	40	40	40	38	38	40	40	40	40	40	40
Maternal dissociation symptoms	r	−0.062	0.069	0.086	0.011	−0.101	−0.003	−0.225	−0.13	−0.203	−0.039	−0.26	−0.035	−0.183	−0.183
	p	0.71	0.681	0.604	0.946	0.54	0.985	0.175	0.437	0.209	0.81	0.105	0.831	0.259	0.259
	N	38	38	39	39	39	39	38	38	40	40	40	40	40	40

* Not significant with FDR correction for multiple comparisons.

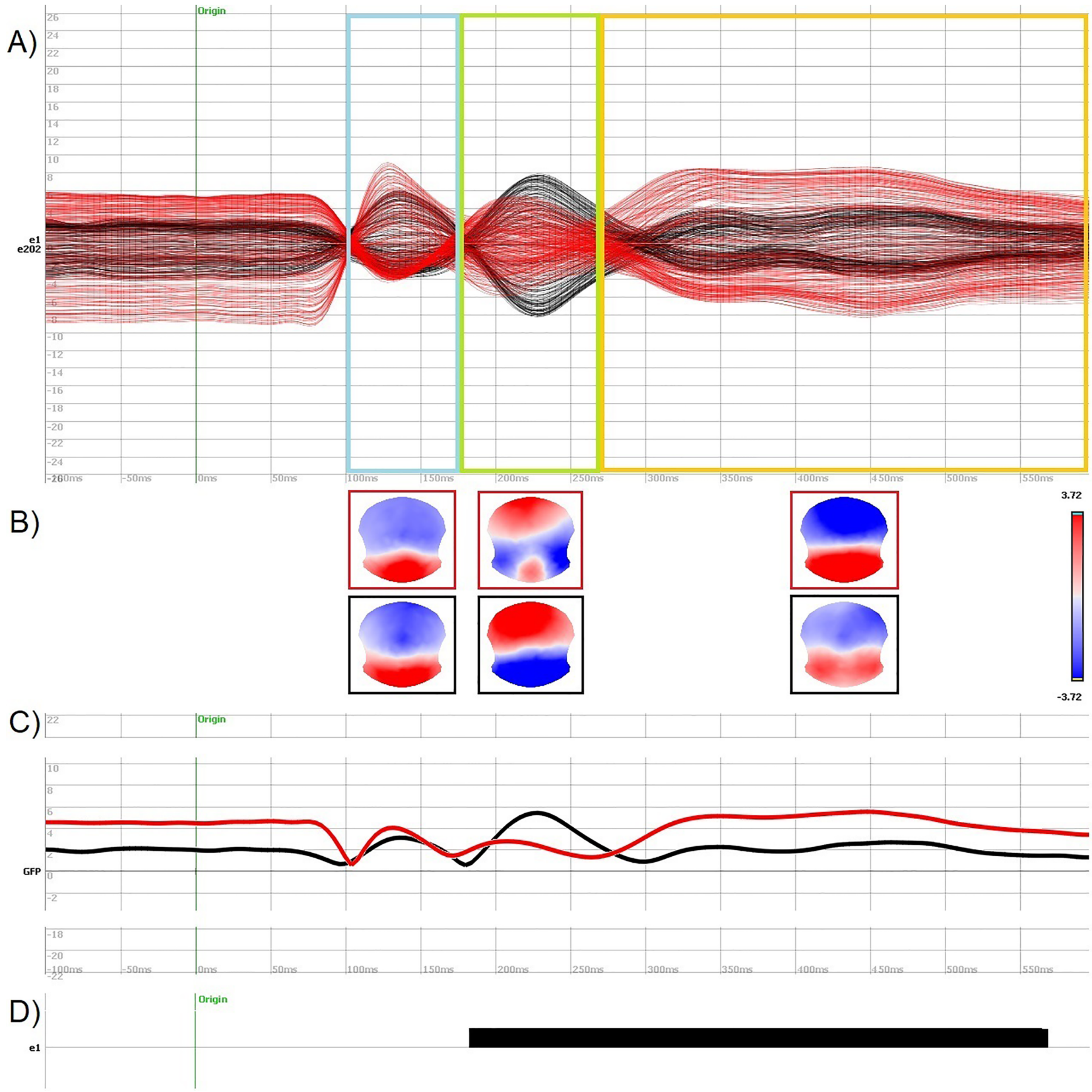

Fig. 2. A) Grand average waveforms (butterfly montage) with highlighted ERP components (P100 in blue, N170/N200 in green and LPP in orange); B) Topographic ERPs maps (red for emotional faces and black for shapes); C) Global Field Power (GFP) measures for each condition (faces in red and shapes in black).
D) Topographical ANOVA (TANOVA) black bar showing significant differences ($p < .01$ and lasting for ≥ 16 ms) between emotional faces and shapes (significant differences were found between 184 and 568 ms after stimulus onset).

decreased activation was also measured in the right cuneus (visual cortex), the latter in response to angry faces among IPV-PTSD children whereas increased activity in the left middle occipital gyrus (visual cortex) in response to happy faces was found in the same group. Results are displayed in Fig. 4. Activation foci, p values and t values measures are summarized in Table 4.

4. Discussion

Maternal IPV-PTSD and the disruption it causes in maternal self-ER and, by extension, in maternal participation in parent-child mutual-ER, contributed to difficulties that were comparable to those of mothers with respect to maternal and child appraisal of facial expressions of emotion.

4.1. Discussion of results relating to Hypothesis 1

Behavioral results confirmed our first hypothesis and demonstrated that maternal PTSD severity was associated with more maternal errors involving confusion between angry and fearful faces on continuous analyses. Hypervigilance to anger among traumatized mothers was specifically associated with maternal IPV-PTSD severity. This finding is similar to those among maltreated children (Curtis and Cicchetti, 2013; Shackman and Pollak, 2014).

Maternal IPV-PTSD was also associated with specific errors in their child's responses on the EFMT. Indeed, children of IPV-PTSD mothers compared to children of non-PTSD controls showed greater confusion between the negative emotions anger and fear. One possible mechanism

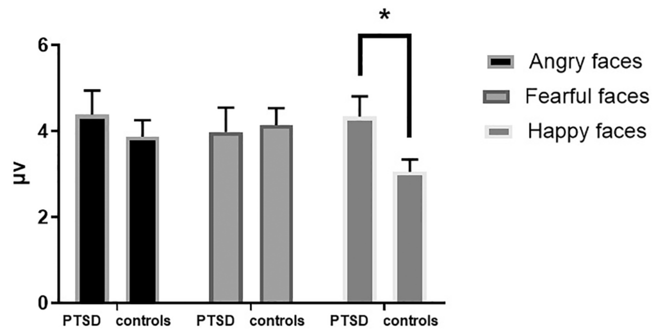

Fig. 3. Global Field Power (GFP) values for each group and conditions at the N170 latency. Asterisk (*) indicates significant group differences.

by which IPV-PTSD related maternal hypervigilance to facial emotion might be communicated is via social, hippocampal-based learning during the sensitive period in early development that corresponds to Phase 1 child ages studied, whereby toddlers must attend to their mother's facial expressions in order to estimate the safety vs danger in their environment (i.e. 12–42 months Alberini and Travaglia, 2017; Travaglia et al., 2016).

We were curious as to why IPV-PTSD mothers vs non-PTSD controls made significantly greater errors in the matching of geometric shapes as a control condition than in the matching of human facial expressions. To put this into perspective, we note that the number of errors in shape-matching was very low in both groups. With this in mind, significant differences between groups and association with maternal PTSD-related symptoms could well be influenced by the repeated exposure to negative affect-related faces, requiring increased attentional resources in mothers exposed to IPV-PTSD, thus leading them to make more errors in shapes matching trials compared to non-PTSD controls. This finding could also be due simply to greater difficulty in concentration and attention among the IPV-PTSD subjects as compared to controls. Attentional difficulty is a common hyperarousal symptom of PTSD, and one that has been particularly noted among other mild cognitive deficits found in women with PTSD (Narita-Ohtaki et al., 2018; Sumner et al., 2017). We also note that the capacity to dissociate or "tune out" as was found to be associated with these shape-identification errors may also contribute to overall EFMT errors by the IPV-PTSD mothers. This would require further study.

4.2. Discussion of results relating to Hypothesis 2

We expected to find altered emotional processing with increased amplitudes of the P1 and N170 components (measured with greater GFP values) in response to negative emotions among children of IPV-PTSD mothers compared to those of non-PTSD controls. Our analysis partially confirmed this hypothesis in that we found significant Group by Emotion interactions for the two ERP components of interest, P1 and N170. More specifically, GFP values pertaining to the N170 component demonstrated that children of non-PTSD mothers showed greater recruitment of brain resources for negative emotions compared to positive emotion. However, children of IPV-PTSD mothers allocated a similar index for all emotions.

We could interpret these findings to mean that children of IPV-PTSD mothers might show hypervigilance in response to all emotions, as measured by a greater amount of global neural synchronization (i.e. corresponding to greater brain resources expended). Child hypervigilance and thus hyperarousal to all emotions, regardless of valence, could be due to a specific characteristic that is linked to the tendency towards unpredictable caregiving and emotion regulation among IPV-PTSD-affected mothers and that translates to observed maternal behavior that is coded as significantly less sensitive, more defensive and self-protective in response to her child's distress (Schechter et al., 2015; Suardi et al., accepted). More broadly, these child results may well be associated with maternal and child impairment in social-emotional information processing (Berke et al., 2017; Zeng et al., 2018).

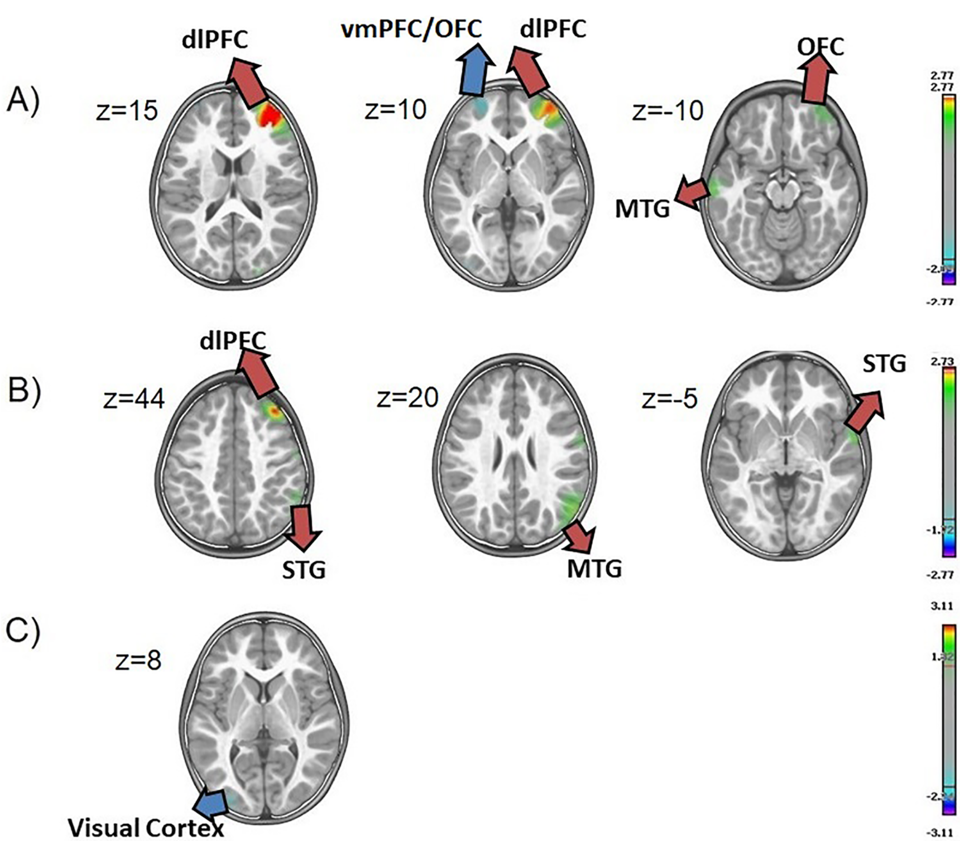

Fig. 4. Source localization of the N170 component based on the Global Field Power (GFP) related to emotional faces (between 176 and 270 ms). Green to red colors indicate current source density decreased activity in children of IPV-PTSD mothers, whereas turquoise to blue colors demonstrated current source density increased activity in children of IPV-PTSD mothers, in response to angry (A), fearful (B) and happy (C) faces.

Table 4
EEG source analysis results: PTSD vs controls for angry, fearful and happy faces.

	Location	Lateralization	MNI x	y	z	BA	p-values	t-values
Angry faces	Dorsolateral prefrontal cortex	R	38	49	9	10	0.005	2.77
	Ventromedial prefrontal cortex/Orbitofrontal cortex	L	−32	66	10	10	0.045	−2.09
	Orbitofrontal cortex	R	31	42	37	9	0.015	2.56
	Inferior temporal gyrus	L	−66	−14	−25	21	0.034	2.18
	Middle temporal gyrus	L	−52	−14	−18	20	0.046	2.11
	Visual cortex	R	17	−87	12	18	0.031	2.35
Fearful faces	Dorsolateral prefrontal cortex	R	38	35	44	8	0.009	2.73
	Dorsolateral prefrontal cortex	R	45	35	37	9	0.046	2.09
	Middle temporal gyrus	R	59	1	−33	39	0.042	2.18
	Middle temporal gyrus	R	69	0	−5	39	0.05	2.01
	Superior temporal gyrus	R	59	−65	24	39	0.046	2.08
	Inferior temporal gyrus	R	51	−4	−39	20	0.036	2.19
	Cerebellum	R	30	−34	−37		0.017	2.54
		L	−49	−69	−46		0.016	2.55
Happy faces	Visual cortex	L	−34	−98	8	18	0.031	−2.24

While increased GFP is typically interpreted as increased global neuronal synchronization, an alternative explanation in terms of ERPs might be that the brain responses to the individual stimuli were more variable in time, so that the averaging across repetitions might lead to lower GFP due to increased temporal smearing.

Beyond this, groups were significantly and specifically different for happy faces only on post-hoc analyses in terms of amplitude of the GFP. Specific bias towards positive emotion in children has already been demonstrated among maltreated children (Curtis and Cicchetti, 2011). In the case of maltreated children, one can hypothesize that this bias is fostered by a predominant negative emotional tone within the family context, and thus altered child capacities in appraising positive affect-related emotions as novel. The child may additionally come to view relatively transient positively valenced, happy emotional expression as a precursor of a more prevalent negatively valenced, angry expression. Previous results obtained among children of maltreated and battered adult mothers with PTSD showed also that they learned to become more hypervigilant to expressions of emotion in general (Dubowitz et al., 2001).

4.3. Discussion of results relating to Hypothesis 3

Results confirmed that children of IPV-PTSD mothers as compared to those of non-PTSD mothers, demonstrated decreased activity in right dorsolateral prefrontal cortex (dlPFC). This finding was in response both to angry and fearful faces. Decreased activation of the dlPFC in response to facial expressions of emotion has clearly been demonstrated as being linked to altered emotional processing in adults and children who have been exposed to maltreatment and other forms of early life stress (Doretto and Scivoletto, 2018; Fonzo et al., 2016). This decreased activation has also been found to be associated with difficulties in disengaging from specific emotional stimuli due to failure in cognitive control and in emotion regulation (Marusak et al., 2015).

While right mPFC activity was not found to be significantly associated with response to facial stimuli, the left vmPFC/OFC was activated in response to angry faces among IPV-PTSD mothers as compared to non-PTSD controls. So, both laterality of prefrontal structures and functional specificity of dlPFC vs vmPFC/OFC areas shows a specific pattern that exposes the likely differences in how the dlPFC vs mPFC subserve top-down regulation of the limbic system responses (Golkar et al., 2012). The literature suggests that the dlPFC is specifically implicated in top-down inhibition and regulation of the amygdala response to fear stimuli; whereas the vmPFC/OFC, comparatively, is more implicated in top-down social-cognitive and autobiographical memory-based processes in order to regulate the limbic system (Ahmed et al., 2015; Ochsner and Gross, 2005). The issue of these lateral differences may reflect a "failure to regulate" response to negative emotional stimuli (Johnstone et al., 2007).

Source localization results demonstrated distinct patterns of activity in the right orbitofrontal cortex (OFC) in response to angry faces. The OFC plays a role in decision-making (Casula et al., 2017) and would confirm that children of IPV-PTSD mothers showed greater difficulty in decision-making than controls, and thus in the identification of a particular facial expression that had been presented along with contrasting facial expressions (angry, fearful or happy faces). The latter was already demonstrated by greater confusion between negative emotions among their children during the EFMT.

EEG source localization findings also demonstrated some unexpected results such as decreased brain activity in the left middle temporal gyrus (MTG) in response to angry faces, and in the right MTG in response to fearful faces, as well as in the right superior temporal gyrus (STG) in response to fearful faces among children of IPV-PTSD mothers. Riedel et al. (2018) considered meta-analytic groupings (MAGs) of brain structures involved in affective processing of visual and auditory stimuli and found that the MTG was part of a larger emotion processing network. The MTG is known to be involved in semantic memory and might be associated with increased difficulties in mentally labelling emotions among children of IPV-PTSD mothers as compared to those of non-PTSD controls. The STG is often considered as a structure involved in social cognition (Bigler et al., 2007; Jou et al., 2010) and might be associated with greater difficulties in emotion identification in these children.

Decreased activity was found in the right cuneus in response to angry faces whereas increased activity in the left visual cortex was also demonstrated among children of IPV-PTSD mothers in response to happy faces. The cuneus is linked to the core face processing network and might thus be involved in the visual decoding of faces (Nagy et al., 2012).

4.4. Limitations

One limitation of the present study was that maternal exposure to interpersonal violence varied significantly in type, age of onset, chronicity, repetitiveness, and degree of injury across subjects. Some children were exposed to domestic verbal and/or physical violence whereas other children in the IPV-PTSD mothers' group were not. The sample was not large enough to take into account this clinical heterogeneity, albeit a very typical and naturalistic representation of women with IPV-PTSD (Afifi et al., 2017; Machisa et al., 2017). Another possible limitation of our study could be the systematic repetition of the facial expressions of emotion as visual stimuli; which has been found in one study to diminish the amplitude of the N170 ERP component (Schweinberger and Neumann, 2016). Despite this possible limitation, our study demonstrated group differences with respect to N170. An additional limitation as mentioned by van Hoof et al. (2017) is that attentional bias to threat in subjects who are exposed to early life stress such as maltreatment or exposure to family violence, while consistent with the existing literature, remains somewhat controversial with respect to the direction of effect. Finally, we have posited that significant group behavioral differences with respect to identification of geometrical shapes (i.e. our control condition) on the EFMT were likely due to group differences in the capacity to concentrate and attend as is characteristic of PTSD. Nevertheless, we cannot rule out that fundamental group behavioral differences, such as that of perception extending beyond emotion appraisal, may have affected results and would thus require further study.

4.5. Conclusion and clinical implications

In conclusion, we have shown that maternal IPV-PTSD is associated both with altered maternal and child processing of facial emotion. The present study is, to our knowledge, the first to show that maternal IPV-PTSD affects a mother's behavioral response to facial expressions of emotion as well as her child's response. These associations were observed both at the level of behavior and at that of neural activity in response to facial expressions of emotion. More specifically, children of IPV-PTSD mothers show enhanced sensitivity to negative emotions. The latter requires further study; namely, of the psychobiological mechanisms by which altered appraisal and discrimination of facial expressions are communicated across generations. The latter is likely to be important in the development and study of effective interventions to interrupt intergenerational cycles of violence and trauma.

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Declarations of interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.pscychresns.2018.11.010.

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