Hypoactive medial prefrontal cortex functioning in adults reporting childhood emotional maltreatment

Anne-Laura van Harmelen,1,2,3 Marie-José van Tol,4,5 Tim Dalgleish,6 Nic J. A. van der Wee,1,4 Dick J. Veltman,7 André Aleman,2 Philip Spinhoven,2,4 Brenda W. J. H. Penninx,5,7 and Bernet M. Elzinga1,2

1Leiden Institute for Brain and Cognition (LIBC), Postzone C2-S, P.O. Box 9600, 2300 RC Leiden, the Netherlands, 2Clinical, Health and Neuropsychology Unit, Leiden University, Pieter de la Court Gebouw, Wassenaarseweg 52, 2333 AK Leiden, the Netherlands, 3Department of Developmental Psychiatry, University of Cambridge School of Clinical Medicine, Box 189 Cambridge Biomedical Campus, Cambridge, UK, CB2 2QQ, 4Department of Psychiatry, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, the Netherlands, 5Neuro-imaging Center, University Medical Center Groningen, and Department of Psychology, University of Groningen, Antonius Deusinglaan 29713 AW Groningen, the Netherlands, 6Medical Research Council, Cognition and Brain Sciences Unit, 15 Chaucer Road, Cambridge, UK CB2 7EF, and 7Department of Psychiatry, VU University Medical Center, A.J. Erasmusstraat 1187, 1081 HL Amsterdam, the Netherlands

Childhood emotional maltreatment (CEM) has adverse effects on medial prefrontal cortex (mPFC) morphology, a structure that is crucial for cognitive functioning and (emotional) memory and which modulates the limbic system. In addition, CEM has been linked to amygdala hyperactivity during emotional face processing. However, no study has yet investigated the functional neural correlates of neutral and emotional memory in adults reporting CEM. Using functional magnetic resonance imaging, we investigated CEM-related differential activations in mPFC during the encoding and recognition of positive, negative and neutral words. The sample (N = 194) consisted of patients with depression and/or anxiety disorders and healthy controls (HC) reporting CEM (n = 96) and patients and HC reporting no abuse (n = 98). We found a consistent pattern of mPFC hypoactivation during encoding and recognition of positive, negative and neutral words in individuals reporting CEM. These results were not explained by psychopathology or severity of depression or anxiety symptoms, or by gender, level of neuroticism, parental psychopathology, negative life events, antidepressant use or decreased mPFC volume in the CEM group. These findings indicate mPFC hypoactivity in individuals reporting CEM during emotional and neutral memory encoding and recognition. Our findings suggest that CEM may increase individuals’ risk to the development of psychopathology on differential levels of processing in the brain; blunted mPFC activation during higher order processing and enhanced amygdala activation during automatic/lower order emotion processing. These findings are vital in understanding the long-term consequences of CEM.

Keywords: Anxiety; childhood abuse; depression; emotional maltreatment; magnetic resonance imaging (MRI); medial prefrontal cortex (PFC)

INTRODUCTION

Childhood emotional maltreatment (CEM; emotional abuse and/or emotional neglect) is experienced by one out of 10 children growing up in Western societies every year (Gilbert et al., 2009), CEM is the most prevalent type of child-maltreatment and has a profound negative impact on social, cognitive, behavioral and emotional functioning (Pollak et al., 2009; Egeland, 2009; Gilbert et al., 2009; Hart and Rubia, 2012; Spinhoven et al., 2010; Schechter, 2012). After chronic exposure to CEM, individuals may develop sustained negative self-associations (Van Harmelen et al., 2010a), which may bias attention toward negative information about the self and others. Even as adults, this may result in negative interpretations when engaged in stressful interpersonal situations, or when retrieving memories of such situations (Beck, 2008). In line, individuals with CEM are more prone to develop depressive and anxiety disorders (Spinhoven et al., 2010; Iffland et al., 2012).

Chronic childhood stress is associated with structural and functional changes in the brain, especially within the (medial) prefrontal cortex [(m)PFC], hippocampus and the amygdala [see overviews and mechanisms; (Arne, 2009; Lupien et al., 2009; Danese and McEwen, 2012; Hart and Rubia, 2012; McCrory et al., 2012; McEwen et al., 2012)]. In line, we reported CEM-related smaller mPFC volume (Van Harmelen et al., 2010b) and amygdala hyperactivation during the processing of emotional faces in patients and healthy controls (HC) (Van Harmelen et al., 2013); see also Bogdan et al. (2012); Danilowska et al. (2012a; 2012b) and McCrory et al. (2011). The mPFC is crucial for emotional processing, memory and modulates the stress response (Cardinal et al., 2002; Phillips et al., 2003; Etkin et al., 2011). The dorsal mPFC plays a vital role in the (re-) appraisal of emotional stimuli, whereas the ventral mPFC dampens fear responses through its regulation of the amygdala (Phillips et al., 2003; Etkin et al., 2011). The dorsal and ventral mPFC are functionally inextricably intertwined, therefore abnormalities in either or both may be associated with abnormalities in emotional processing, memory and stress response (Phillips et al., 2003; Etkin et al., 2011). The mPFC is also crucial for understanding other people’s beliefs, feelings and motivations (i.e. mentalizing) (Frith & Frith, 2003; Frith and Frith, 2006; Mitchell et al., 2006; Denny et al., 2012; Meyer et al., 2013). In children, a smaller PFC volume has been found to mediate the link between childhood stress and reduced cognitive functioning (Hanson et al., 2012). However, the neural correlates of cognitive functioning in adults reporting CEM are unknown.

During and immediately after acute interpersonal stress, brain activity shifts from higher cortical (e.g. mPFC) regions to ‘lower’ subcortical regions (e.g. amygdala, hippocampus) (Hermans et al., 2011; Oei et al., 2012). Stress activates the amygdala as part of a 'salience
network' for vigilant attentional reorienting, strengthening of emotional memory traces and autonomic-neuroendocrine control, facilitating the processing/encoding of emotional information, at the detriment of higher order cognitive functions (Davis and Whalen, 2001; Whalen, 2007; Hermans et al., 2011; Todd et al., 2011; Oei et al., 2012). In HCs, exposure to acute psychosocial stress increases coupling of mPFC and amygdala activations, which persists even some time after the stress has waned (Veer et al., 2011). To investigate whether CEM is related to a reduction in higher order cognitive functioning, the functional neural correlates of CEM during cognitive tasks that are known to engage frontal regions need be examined.

Here, we examined the neural correlates of CEM during the encoding and recognition of (positive, negative and neutral) words in a large sample (N = 194), by comparing patients and HC reporting CEM ([n = 96; i.e. patients with major depressive disorder (MDD; n = 20), anxiety disorder (ANX; n = 27), co-morbid depression and anxiety disorder (CDA; n = 40) and HC n = 9]), with those reporting no abuse ([n = 98; i.e. MDD (n = 24), ANX (n = 22), CDA (n = 19) and HC (n = 33)]. We expected that self-reported CEM was associated with a memory bias (i.e. relative enhanced recognition) with respect to negative stimuli and limbic (amygdala and hippocampal) hyperactivations during encoding and recognition of negative words, but not for positive or neutral words. In addition, we expected a general reduction in cognitive functioning in individuals with CEM, associated with overall reduced mPFC activations (across valence).

**METHOD**

**Participants**

Participants were a subset from the Netherlands Study of Depression and Anxiety [NESDA; N = 2981; (Penninx et al., 2008)], consisting of 233 patients with MDD and/or ANX and 68 HC. Participants underwent magnetic resonance imaging (MRI) scanning in the Leiden University Medical Center (LUMC), Academic Medical Center Amsterdam (AMC) or University Medical Center Groningen (UMCG). Trained interviewers established diagnoses using the structured Composite International Diagnostic Interview (Wittchen et al., 1991). Patients were included when they had a diagnosis <6 months recency of current DSM-IV MDD and/or ANX (panic disorder and/or social anxiety disorder). Patients were excluded if they were taking any psychotropic medication other than stable use of selective serotonin reuptake inhibitors (SSRIs) or infrequent benzodiazepine use (i.e. equivalent to two doses of 10 mg of oxazepam three times per week or use within 48 h prior to scanning). HCs had no lifetime MDD or ANX and were not taking any psychotropic drugs. Ethical Review Boards of each participating center approved this study, and after complete description of the study, written informed consent was obtained.

**Childhood maltreatment**

Childhood maltreatment was assessed through the NEMESIS trauma interview (De Graaf et al., 2002). Participants were asked whether they had experienced emotional neglect, emotional abuse, physical abuse or sexual abuse before the age of 16 years, and if so, how often it occurred (‘never, once, sometimes, regularly, or very often’), and what their relationship with the perpetrator was. Emotional neglect was described as: ‘people at home didn’t listen to you, your problems were ignored, and you felt unable to find any attention or support from the people in your house’. Emotional abuse was described as: ‘you were cursed at, unjustly punished, your brothers and sisters were favored – but no bodily harm was done’. CEM was defined as multiple incidents (more than once) of emotional neglect and/or emotional

**Table 1** Demographics, clinical characteristics and memory performance of the No Abuse and CEM groups

<table>
<thead>
<tr>
<th>Characteristics and performance</th>
<th>No Abuse (N = 98)</th>
<th>CEM (N = 96)</th>
<th>$\chi^2$</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean (s.d.))</td>
<td>36.48 (10.56)</td>
<td>38.11 (9.52)</td>
<td>1.28</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Gender (male/female) (n)</td>
<td>57/41</td>
<td>60/36</td>
<td>0.73</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Education level (years)</td>
<td>13.16 (2.88)</td>
<td>12.5 (3.28)</td>
<td>0.50</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Scan location (A/L/G) (n)</td>
<td>30/37/31</td>
<td>32/38/26</td>
<td>0.00</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>Diagnosis (yes/no) (n)</td>
<td>65/33</td>
<td>87/9</td>
<td>16.88</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Diagnosis (MDD/CDA/ANX/HC) (n)</td>
<td>24/19/22/33</td>
<td>20/40/27/9</td>
<td>22.04</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Frequency of CEM (Som/Reg/Often/Often) (n)</td>
<td>21/77</td>
<td>29/67</td>
<td>1.95</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Proportion words classified as neutral</td>
<td>98.94 (24.04)</td>
<td>98.37 (22.35)</td>
<td>0.03</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Proportion words classified as negative</td>
<td>96.97 (5.68)</td>
<td>96.07 (11.39)</td>
<td>0.45</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Proportion words classified as positive</td>
<td>103.14 (24.52)</td>
<td>102.77 (25.03)</td>
<td>0.01</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Proportion correctly recognized positive words</td>
<td>0.73 (0.13)</td>
<td>0.73 (0.15)</td>
<td>0.01</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Proportion correctly recognized negative words</td>
<td>0.69 (0.13)</td>
<td>0.69 (0.16)</td>
<td>0.07</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Proportion correctly recognized neutral words</td>
<td>0.69 (0.15)</td>
<td>0.71 (0.17)</td>
<td>1.41</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Proportion false alarms positive words</td>
<td>0.12 (0.10)</td>
<td>0.11 (0.09)</td>
<td>0.03</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Proportion false alarms negative words</td>
<td>0.17 (0.11)</td>
<td>0.15 (0.10)</td>
<td>1.27</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Proportion false alarms neutral words</td>
<td>0.06 (0.06)</td>
<td>0.06 (0.05)</td>
<td>0.00</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>Discriminant sensitivity positive words</td>
<td>0.61 (0.16)</td>
<td>0.62 (0.15)</td>
<td>0.04</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Discriminant sensitivity negative words</td>
<td>0.52 (0.12)</td>
<td>0.54 (0.14)</td>
<td>1.40</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Discriminant sensitivity neutral words</td>
<td>0.65 (0.16)</td>
<td>0.65 (0.17)</td>
<td>1.37</td>
<td>0.24</td>
<td></td>
</tr>
</tbody>
</table>
abuse (in line with our previous studies, e.g. van Harmelen et al., 2010b, 2013). In the final sample (N = 194, Table 1; additional exclusion criteria in Supplementary Data), 96 adults reported CEM (n = 20 MDD, n = 27 ANX, n = 40 CDA, n = 9 HC) and 98 reported no abuse (n = 24 MDD, n = 22 ANX, n = 19 CDA, n = 33 HC). This is largely the same cohort in whom we found CEM-related reduced mPFC volume (Van Harmelen et al., 2010b) and enhanced amygdala responses (Van Harmelen et al., 2013). In the CEM group, participants reported isolated emotional neglect (n = 46, 47.9%), isolated emotional abuse (n = 3, 3.1%) or both emotional neglect and emotional abuse (n = 47, 49.0%) in childhood. In addition, 95 participants (99.0%) reported their biological parents as perpetrators, one person (1.0%) reported a stepfather as perpetrator.

Additional assessments

In the NESDA study, we assessed lifetime negative life events with the List of Threatening Events Questionnaire (Brugha et al., 1985) and Neuroticism with the NEO Five-Factor Inventory (Costa and McCrae, 1992). Parental psychopathology was assessed using a family tree approach interview, assessing whether a member of their family had experienced anxiety, depression or other psychopathological problems, and if so, which member of their family. On the day of scanning (~8 weeks following NESDA baseline assessment), severity of depression and anxiety (last 2 weeks) was assessed using the Beck Anxiety Inventory (BAI; Beck et al., 1988) and the Montgomery Åsberg Depression Rating Scale (MADRS; Montgomery and Asberg, 1979).

Task paradigm

The word-encoding and -recognition task was event-related, subject-paced (max 5 s) (Daselaar et al., 2003) (Supplementary Data). During encoding, participants were asked to classify 40 positive, 40 negative and 40 neutral words according to their valence. During a baseline control condition, participants viewed the words ‘left’, ‘middle’ or ‘right’ and were instructed to press the corresponding key. After a control condition, participants viewed the words ‘left’, ‘middle’ or ‘right’ and were instructed to press the corresponding key. After a baseline control condition, participants viewed the words ‘left’, ‘right’ and were instructed to press the corresponding key. After a 10 min retention interval, participants indicated whether they had ‘seen’ (i.e. remembered), ‘probably had seen’ (i.e. know), or ‘hadn’t seen’ (i.e. rejection) 120 old encoding target words, 120 new distracter words and 40 baseline control trials. Trial presentation was pseudo-randomized. We recorded response accuracy and times (RT). Anxiety levels were recorded before and after word encoding and recognition using a Visual Analogue Scale (0–100; Huskisson, 1993).

Image acquisition

Imaging data were acquired using Philips 3-Tesla MRI-systems (Best, The Netherlands) located at the LUMC, AMC and UMC, equipped with SENSE-8 (LUMC, UMC) and SENSE-6 (AMC) channel head coils. Echo-planar images were obtained using a T2*-weighted gradient echo sequence [repetition time (TR) = 3200 ms; echo time (TE) = 30 ms (UMCG: 28 ms), matrix size: 96 × 96 (UMCG: 64 × 64), 35 axial slices (UMCG: 39), interleaved acquisition, 2.29 × 2.29 mm in-plane resolution (UMCG: 3 × 3 mm), 3 mm slice thickness]. Anatomical imaging included a sagittal three-dimensional gradient-echo T1-weighted sequence (TR = 9 ms, TE = 3.5 ms; matrix 256 × 256; voxel size: 1 × 1 × 1 mm; 170 slices).

Imaging data

Functional imaging data were pre-processed in Statistical Parametric Mapping software (SPM5) in Matlab7.1 (www.mathworks.co.uk) and analyzed using SPM8 in Matlab7.8. Pre-processing of the imaging data included reorientation of the functional images to the anterior commissure, slice time correction, image realignment, registration of the T1 scan to the mean image, warping to Montreal Neurological Institute (MNI)-space as defined by the SPM5 T1-template, reslicing to 3 × 3 × 3 mm voxels and spatial smoothing using an 8 mm FWHM Gaussian kernel. Next, data were analyzed in the context of the General Linear Model. Hemodynamic responses to each stimulus were modeled with a delta function convolved with a synthetic hemodynamic response function and modulated using RT. The model included regressors for encoding and recognition parameters. In addition, filler words, error- and no-response trials were included as a regressor of no interest. Low-frequency noise was removed by applying a high-pass filter (cut-off: 128 s) to the fMRI time-series at each voxel. Owing to the small proportion of ‘know responses’ on the recognition trials, these responses were treated as ‘remembered’ and added to either correct recognition (CREC) or false alarms (FA).

Contrast images for subsequently correctly recognized (SCR) words during encoding (SCR_pos > baseline, SCR_neg > baseline, SCR_neu > baseline) and CREC words during recognition (CREC_pos > baseline, CREC_neg > baseline and CREC_neu > baseline) were calculated per subject on a voxel-by-voxel basis and entered into second-level analyses for between-group comparisons.

We next set up CEM (No Abuse, CEM) × Words (Positive, Negative, Neutral) RM ANCOVAs for the encoding and recognition task separately. Age, gender and education level were specified as covariates (Idaka et al., 2002; Hart and Rubia, 2012) and two dummy variables were added as covariates to control for variation caused by the different scanning locations. To examine if CEM-related word encoding and recognition was confounded by individual’s psychiatric status, we also added a dummy for current MDD, ANX (yes/no), demeaned within the CEM and No Abuse group to control for variation caused by psychopathology. As only nine HC reported CEM, we were unable to perform group (MDD, ANX, CDA, HC) × CEM (No Abuse, CEM) RM ANOVAs, as these analyses would be seriously underpowered. For the specific effects of MDD, ANX and HC on word encoding and recognition in largely the same sample, see van Tol et al. (2012).

We defined the following ROIs: hippocampus, amygdala, and mPFC. Because the anatomical location of the mPFC is less well defined than that of the hippocampus and amygdala, we focused on the mPFC in the broadest sense (i.e. dorsal mPFC (Brodmann area (BA) 8 and 9), ventral mPFC (BA 10), dorsolateral mPFC (BA 8, 9, and 46), and the dorsal and pregenual ACC (BA 32, 24), using the AAL toolbox implemented in the Wake Forest University (WFU)-Pickatlas (Maldjian et al., 2003). The main effects of task are reported at P < 0.05, Family Wise Error (FWE) (voxel level). Activations outside our ROIs were examined using whole-brain analyses at P < 0.05 FWE corrected, while masking for the main effect of task (P < 0.05 uncorrected). All results are reported in MNI space.

Bilateral Amygdala (131 voxels) and hippocampal (536 voxels) activations were examined by extracting their activations for the main effect of task (F) to SPSS using Marsbar (Brett et al., 2002) and binary masks using WFU-Pickatlas. MPFC activations were examined using CEM vs No Abuse (F) analysis at P < 0.005, uncorrected and post hoc t-tests had to meet P < 0.05 FWE corrected for the spatial extent of the activated region with an initial height threshold of Z > 3.09, and K > 5 voxels, while masking for the main effect of task (P < 0.05 uncorrected). For this small volume correction (P_vcor) we used the WFU-pickatlas and to extract significant mPFC activations for the main effect of task to SPSS we used the Marsbar Toolbox.

References

1. SCR_pos, SCR_neg, SCR_neu, SMISS_pos, SMISS_neg, SMISS_neu, BL (SCR = subsequently correct; SMISS = subsequently missed).

2. CREC_pos, CREC_neg, CREC_neu, CREJ_pos, CREJ_neg, CREJ_neu, FA_pos, FA_neg, FA_neu, WMISS_pos, BL (CREC = Correct recognition; CREJ = correct rejections; WMISS = misses).
mPFC hypoactivity in adults reporting CEM

Behavioral analyses
Psychometric and performance data were analyzed with SPSS-19. Proportions (p) Correctly Recognized words (pCREC), False Alarms (pFA) and old/new discriminant accuracy (d' = pCREC - pFA) were calculated for positive, negative and neutral words. For all tests, significance was set at P < 0.05 two-tailed, Bonferroni-corrected.

RESULTS
CEM vs No Abuse group characteristics and memory performance
The CEM vs No Abuse groups did not differ in age, education, gender, SSRI-use, scan location and anxiety levels before and after the task. The CEM group included more patients, reported higher depressive and anxious symptomatology, higher neuroticism scores, more lifetime negative life events and slightly more parental psychopathology (Table 1). RM ANOVAs revealed no differences in valence classification,3 memory performance or RTs, between the CEM and No Abuse groups (Table 1 and Supplementary Table S1).

Imaging results
Main effect of task during word encoding
The main effect of task during encoding was associated with bilateral amygdala (K = 6, x = -18, y = -6, z = -18, Z-score (Z) = 6.73) and (K = 1, x = 24, y = -9, z = -15, Z = 5.38)), hippocampal (K = 174, x = -21, y = -15, z = -18, Z = 8, K = 60, x = -21, y = -15, z = -21, Z = 6.97), (K = 31, x = 21, y = -12, z = -18, Z = 6.93) and mPFC activations (K = 740, x = -6, y = 60, z = 30, Z = 8); (K = 57, x = -27, y = 0, z = 57, Z = 7.67) and (K = 38, x = -39, y = 36, z = 30, Z = 6.45). Supplementary Table S2 depicts main effect of task activations outside our ROIs.

CEM and word encoding: amygdala and hippocampus
Extracted amygdala and hippocampal activations for the main effect of task (SCR_pos > baseline, SCR_neg > baseline and SCR_neu > baseline) were analyzed in a CEM (No Abuse, CEM) × Words (Positive, Negative, Neutral) × Lateralization (Left, Right) RM ANCOVA, with psychiatric status (demeaned within group), age, gender, education level and dummies for location as covariates. Contrary to our expectations, there were no significant main or interaction effects of CEM [amygdala (F-values < 1.41, all P-values > 0.24) and hippocampus (F-values < 2.69, P-values > 0.10), details in Supplementary Data].

CEM and word encoding: mPFC
A CEM vs No Abuse analysis showed CEM-related mPFC hypoactivation during the encoding of positive, negative and neutral words (K = 26, x = -3 y = 45 z = 33, Z = 3.91, P SVC = 0.024; Figure 1).4 No other clusters were found in or outside our ROIs (Table 2).

A CEM (No Abuse, CEM) × Words (positive, negative, neutral) RM ANCOVA on extracted mPFC activations in this cluster, with psychiatric status (demeaned within group), age, gender, education level and dummies for location as covariates showed, besides the main effect of CEM [F(1, 186) = 11.26, P = 0.001], a marginal main effect of Words [F(2, 372) = 2.78, P = 0.06]. Positive words elicited more mPFC activation (mean = 0.28, s.e. = 0.04) compared with neutral (mean = 0.16, s.e. = 0.05, P < 0.01), but not negative words (mean = 0.25, s.e. = 0.04, P = 0.70). No other differences were found (P-values > 0.11). There was no Words × CEM interaction neither other significant main nor interaction effects (F-values < 2.19, P-values > 0.13). Current psychiatric status had a main effect on mPFC activation [F(1, 186) = 7.93, P = 0.01]; HC had more mPFC activations than patients (t-values > 2.75, P-values < 0.007).

Additional covariances analyses showed that the main effect of CEM remained significant when we co-varied for depression or anxiety severity, neuroticism scores, parental psychopathology, negative life events, concurrent physical and/or sexual abuse, antidepressant medication use or mPFC volume in the CEM group (see Supplementary Data).

Finally, to investigate the functional connectivity of this mPFC cluster (x = -3 y = 45 z = 33) in individuals with CEM (compared with No Abuse), we performed a psycho-physiological interaction (PPI) analysis (specifics in Supplementary Data; Friston et al, 1997).5 Across participants, the PPI showed positive connectivity with the right amygdala (K = 9, x = 21, y = 0, z = -15, Z = 3.87, P svc < 0.004) and left hippocampus (K = 17, x = -24, y = -12, z = -18, Z = 3.97, Psvc < 0.02). No negative connectivity was found with our ROIs. However, no differential connectivity was found for the CEM vs No Abuse groups within our ROIs (Supplementary Data and Supplementary Table S3).

Recognition
Main effect of task during word recognition.

The main effect of task during recognition was associated with mPFC activations (K = 129, x = -3, y = 27, z = 48, Z = 6.85): (K = 54, x = -30, y = -3, z = 57, Z = 6.71); (K = 45, x = 3, y = 63, z = 3, Z = 6.57); (K = 51, x = 33, y = 48, z = 30, Z = 6.46), (K = 5, x = 0, y = 9, z = 39, Z = 4.79), but neither with amygdala nor hippocampal activations. Supplementary Table S2 displays task activations outside our ROIs.

Impact of CEM on word recognition in the mPFC
A CEM vs No Abuse analysis showed CEM-related mPFC hypoactivation during the correct recognition of positive, negative and neutral words (K = 152, x = -6 y = 48 z = 39, Z = 4.18, PSVC = 0.007, Figure 1). No other significant clusters were found in or outside our ROIs (Table 2).

Next, we performed a CEM (CEM vs No Abuse) × Words (Positive, Negative, Neutral) RM ANCOVA on extracted mPFC activations, with psychiatric status (demeaned within group), age, gender, education level and dummies for location as covariates. Besides the main effect of CEM [F(1, 186) = 18.34, P < 0.001], there was no main effect of Words [F(2, 372) = 0.04, P = 0.96]. Psychiatric status did have a main effect [F(1, 186) = 9.25, P = 0.003], with HCs having higher mPFC activations than patients (t-values > 3.54, P-values < 0.001). Furthermore, gender had a marginal main effect [F(1, 186) = 3.53, P = 0.06], with males having marginally more mPFC activation than females for positive words (t = 1.74, P = 0.08), but not for negative or neutral words (t-values < 1.48, P-values < 0.14). Location had a significant main effect [i.e. AMC = [F(1, 186) = 5.24, P = 0.02] and LUMC = [F(1, 186) = 3.62, P = 0.06]. Participants scanned at the AMC had marginally more mPFC activation for negative words (t = 1.90, P = 0.06), but not for positive or neutral words (t > 1.14, P-values > 0.26). Post hoc t-tests showed that participants scanned in Leiden did not have more mPFC activation (all t > 1.40, all P-values > 0.16). There was no Words × CEM interaction, neither other main nor interaction effects (Fs < 1.82, P-values > 0.16).

Footnotes:
1For the word classification task, data from 16 individuals were missing (six reported No Abuse).
2The mPFC activations for encoding and recognition were small-volume corrected using a mask based on the left superior frontal medial cortex, SPM8 voxel, region based on AAL toolbox.
3Due to technical problems with fMRI data of three participants (one reported CEM), we could not include these participants in the PPI analyses.
Follow-up covariance analyses showed that CEM-related hypoactivation could not be explained by more depression or anxiety severity, neuroticism scores, parental psychopathology, negative life events, concurrent physical and/or sexual abuse, antidepressant medication use or mPFC volume (Supplementary Data).

Finally, a PPI analysis in this mPFC cluster (x = −6, y = 48, z = 39), revealed positive connectivity with the left amygdala (K = 11, x = −27, y = 0, z = −18, Z = 3.64, P svc < 0.009) and left hippocampus (K = 22, x = −21, y = −12, z = −24, Z = 4.98, P svc < 0.005), but no negative connectivity with the mPFC, across participants. Finally, no CEM-related differential connectivity was found within our ROIs (Supplementary Data and Supplementary Table S4).

**DISCUSSION**

We show consistent CEM-related mPFC hypoactivation during the encoding and recognition positive, negative and neutral words, a
mPFC hypoactivity in adults reporting CEM

task that requires higher order cognitive processing. Our findings
cannot be explained by CEM-related higher levels of neuroticism, par-

etal psychopathology, negative life events, concurrent physical and/or

sexual abuse, antidepressant medication use or smaller mPFC volume
(Van Harmelen et al., 2010b). In addition, the mPFC hypoactivations
were not accounted for by psychiatric status, or by higher depressive or

anxiety symptoms, despite the fact that the CEM group contained
more patients and those patients showed mPFC hypoactivation com-
pared with HC.

Contrary to our predictions, limbic activations were not enhanced
and PPI analyses showed no CEM-related differential mPFC–amygdala
coupling either. Therefore, and together with findings of CEM-related

amygdala hyperactivity to facial expressions (McCrory et al., 2011,
2013; Bogdan et al., 2012; Dannowski, et al. 2012a,b; Van Harmelen
et al., 2013), these findings suggest that individuals reporting CEM

show hypoactive mPFC activation during cognitive processing/evalu-

ation for meaning/content (subservied by the mPFC) and hyperactive

amygdala activation in response to emotionally demanding tasks or

contexts, which require amygdala processing. Interestingly, this pattern
of findings resembles those of studies on the impact of acute stress
exposure, showing that stress exposure induces a shift from higher
cognitive to more habitual/emotional processes and related neural sys-

tems (PFC vs limbic regions) (Hermans et al., 2011; Oei et al., 2012).

Individuals reporting CEM showed similar response accuracy and
RTs for positive, negative and neutral words. Thus, although enhanced
negative stimuli processing and related brain activations have been
reported in depressed individuals (see for an overview: Groenewold
et al., 2013), and in post-traumatic stress disorder (PTSD) (see for an
overview: Brown and Morey, 2012), we did not find support for CEM-
related biased processing of negative stimuli. It is unclear whether this
reflects a lack of biased processing, or whether the task at hand was not
sensitive enough to detect biases. The classification task did not assess
appraisal of the words; hence, even though participants know how to
accurately categorize the words they may still appraise them as more
negative. In addition, recognition was assessed after a short (10 min)
retention interval, making our task prone to performance ceiling ef-

fects that may obscure performance biases.

We found CEM-related mPFC hypoactivation across valence, how-

ever, on a behavioral level, we did not find similarly reduced cognitive
processing. The CEM group was as accurate and fast in categorizing
words as the No Abuse group. Hence, mPFC hypoactivation in indi-

viduals reporting CEM may resemble a more general blunting of cog-
nitive processing in these individuals; individuals reporting CEM may
require less cognitive and related mPFC processing in order to cor-
rectly recognize words later on. It is unknown whether this overall
blunting of mPFC activation translates to other cognitive domains,
which one might expect given that the mPFC is also implicated in
self-referential processing and mentalizing (Frith et al., 2003; Frith
and Frith, 2006; Mitchell et al., 2006; Denny et al., 2012; Meyer
et al., 2013). Future studies are needed to investigate whether CEM-
related mPFC hypoactivation is related to dysfunctions in these forms
of social cognitive processing, as this may have important clinical
implications.

Some limitations need to be taken into account. First, retrospective
self-reported CEM is innately subjective and patients may over-report
CEM histories. However, maltreatment history is more likely to be
under- than over-reported (Hardt and Rutter, 2004; Brewin, 2007),
and in the NESDA sample (N = 2981), CEM recall was not affected
by current mood state (Spinheven et al., 2010). Moreover, a history
of maltreatment (including emotional abuse and emotional neglect)

based on the NEMESIS trauma interview has been associated with
an increased incidence and prevalence of psychiatric disorders, sug-

gesting that the NEMESIS trauma interview has good construct

validity (e.g. de Graaf et al., 2002; 2004; Wiersma et al., 2009;
Hovens et al., 2010; Spinheven et al., 2010; van Harmelen et al.,
2010a). Furthermore, in a confirmatory factor analysis, type of abuse
on the NEMESIS trauma interview showed loadings on latent con-

structs for abuse type comparable with the loading of analogous sub-

scales of the childhood trauma questionnaire (CTQ, Thomsbs et al.,
2009), which is a well validated and reliable questionnaire on child-

hood trauma (Thomsbs et al., 2009) (Spinheven et al., submitted for
publication). In addition, compared with the CTQ, CEM is more likely
to be under-reported than over-reported in the NEMESIS trauma
interview and patients were shown to be somewhat more consistent
in their reports than individuals without psychopathology (Spinheven
et al., submitted for publication).

Second, IQ was not assessed as a potential confound in our analyses.
However, education level, which is highly correlated with IQ (r = 0.88;
Gottfredson, 1997), did not explain our findings. Third, although the
effects of CEM on brain functioning remain after regressing out im-
portant potential confounds such as psychopathology, parental psy-
chopathology and neuroticism, comparing the CEM and No Abuse
groups is intrinsically confounded by these factors and in the context
of GLM, only linear components of such effects are addressed this way.
Regressing out confounders cannot fully solve this problem and future
studies may have to address this issue by directly comparing, for ex-
ample, individuals with CEM and high levels of psychopathology vs
individuals with CEM and no psychopathology. Fourth, contrary to
our expectations, we did not find significant hippocampal or amygdala
activations related to CEM during word encoding and retrieval. And
although hippocampal and amygdala activations during word encod-
ing and recognition in largely the same sample have been linked to
psychopathology (van Tol et al., 2012), we cannot rule out the possi-
bility that our null findings regarding the impact of CEM in these
regions may be due to the design of our study, namely a multi-site
MRI collaboration. A multi-site MRI study may increase between-sub-
ject variability due to different scanner specifications and may there-
fore decrease sensitivity in detecting small effects. However, previous
work on largely the same (multi-site) sample (see van Harmelen et al.,
2013) found CEM-related increased activation in the amygdala during
emotional face processing. This suggests that our multi-site design is
sensitive enough to identify overall group differences, and hence
cannot fully explain the lack of effects in the amygdala and hippocam-
pus in the context of word encoding. Fifth, our cross-sectional design
obscures causality inferences; mPFC hypoactivation may have been
present before CEM and may even been a pre-disposing factor that
enhances parental risk to emotionally maltreat their children.
However, continuing this line of reasoning, it might be expected that
parental psychopathology is related to our findings, and it was not.
Theoretically, only longitudinal studies can disentangle the impact of
CEM from its pre-disposing factors. However, these studies are highly
problematic from an ethical point of view, hence, our cross-sectional
study with a large sample of patients and HC’s and control of many
potential confounds is a good alternative.

CONCLUSION
We found that CEM is related to mPFC hypoactivation during the
encoding and recognition of positive, negative and neutral words.
This was not explained by higher depression or anxiety symptoms,
neuroticism, parental psychopathology, negative life events, anti-
depressant use or by mPFC volume. Together with previous findings
of CEM-related smaller mPFC volume (Van Harmelen et al., 2010b)
and amygdala hyperactivity to facial expressions (McCrory et al., 2011,
2013; Bogdan et al., 2012; Dannowski et al., 2012a,b, submitted for
publication; Van Harmelen et al., 2012), these findings suggest that
CEM increases individuals’ risk to the development of psychopathology (Spinhowen et al., 2010; Iffland et al., 2012) on differential levels of processing in the brain; mPFC hypoparticulation during cognitive processing or more basal amygdala hyperactivation during emotion processing. Therefore, our findings add substantively to the understanding of the long-term impact of CEM.

SUPPLEMENTARY DATA
Supplementary data are available at SCAN online.

Conflict of Interest
None declared.

REFERENCES


