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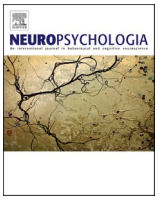

What a cute baby! Preliminary evidence from a fMRI study for the association between mothers' neural responses to infant faces and activation of the parental care system

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ABSTRACT

Infant facial characteristics, i.e., baby schema, are thought to automatically elicit parenting behavior and affective orientation toward infants. Only a few studies, conducted in non-parents, have directly examined the neural underpinnings of this baby schema effect by manipulating distinctiveness of baby schema in infant faces. This study aims to further our understanding of the intuitive nature of parenting, by studying the baby schema effect in mothers of young children (at least one child aged between 2 and 6 years old). Functional magnetic resonance imaging (fMRI) was used to examine mothers' ($N = 23$) neural responses to unfamiliar infant faces varying in distinctiveness of baby schema. Also, it was studied how this neural activation to infant faces was associated with maternal nurturance. Results revealed that infant faces elicited widespread activation in bilateral visual cortices, the hippocampus, sensory-motor areas, parietal and frontal cortices, and the insula, which was not modulated by the distinctiveness of baby schema in the infant faces. Furthermore, higher self-reported maternal nurturance was related to increased neural responses to infant faces in the putamen and amygdala, brain regions known to be associated with reward and salience processing. These findings could suggest that in our small sample of mothers some of the core networks involved in reward and salience processing might be less sensitive to variation in distinctiveness of baby schema. Also, unfamiliar infant faces seem to be rewarding only for mothers who report high nurturance. These findings should be considered preliminary, because they need to be replicated in studies with larger samples.

Author statement

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1. Introduction

Adults, as well as children, appear to have a natural interest and attraction to human and animal babies. According to Lorenz (1943), this is because infants possess certain facial characteristics called baby schema, such as a large forehead, big eyes, chubby cheeks, and a small nose and mouth. Baby schema are thought to elicit caretaking and orienting responses to infants, and reduce aggression toward infants, with the evolutionary function of increasing the survival chances of infants (Glocker et al., 2009; Lorenz, 1943; Luo et al., 2011). There is ample evidence that baby schema are associated with positive emotions, increased ratings of cuteness, and caretaking behaviors in parents, adult non-parents, and even children (for review, see Luo et al., 2015). Recently, neuroimaging studies have tried to uncover the neural correlates of the behavioral and emotional responses associated with baby schema (Bos et al., 2018; Glocker et al., 2009). However, very few neuroimaging studies have directly examined the influence of baby schema (Luo et al., 2015). When the baby schema effect was investigated, the data were collected in non-parents.

Neuroimaging research in parents is important to increase our understanding of intuitive, automatic, and affective processes underlying parenting (Parke, 2017). Examining baby-schema effects in parents who

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actually have experience with their own infants, is an important and ecologically valid addition to the previous work on baby schema that mostly has been conducted in non-parents. There is some evidence that parental experience modulates neural and attentional responses to infants (Mascaro et al., 2014; Proverbio et al., 2006; Thompson-Booth et al., 2014; Weisman et al., 2012). Therefore, in the current study we examined mothers' neural responses to unfamiliar infant faces varying in distinctiveness of baby schema using functional magnetic resonance imaging (fMRI). We also examined whether individual differences in neural responses to infant faces reflected variation in activation of the parental care system by infant cues. Future work can build further on this by running comparative or developmental studies, or by linking neural processing of infant cues to actual caregiving behavior (e.g., Endendijk et al., 2018). When parents' neural responsiveness to baby schema indeed appears to be an important predictor for the quality of parental care, the baby schema effect might be used to screen parents at risk for showing less optimal caregiving behavior or to determine the effectiveness of parenting interventions. Parenting interventions could then also focus on increasing the perceived reward value of infant facial cues (i.e., cuteness), which has been found to be modifiable through experience (Parsons et al., 2014; Stark et al., 2019).

Parents' sensitivity to subtle variations in infant facial characteristics is a particularly important determinant of parenting, as parents need to be able to respond appropriately to subtle facial cues as well as to more obvious cues, like crying or smiling (Biringen, 2008). In addition, attention to child facial cues might facilitate the detection and interpretation of a child's signals, which is an essential prerequisite for sensitive parenting behavior across development (Ainsworth and Bell, 1970). Therefore, we argue that parental responsiveness to variations in baby schema represents a first manifestation and a proxy for general responsiveness to child cues. As such, responsiveness to baby schema might set the stage for parenting infants as well as older children. Previous longitudinal research has demonstrated the relative consistency of parenting behaviors, such as sensitive responsiveness, from infancy to early childhood (Hallers-Haalboom et al., 2017). This indicates that parents who are highly responsive with infants, possibly because of their high responsiveness to baby schema, are likely to be highly responsive with older children, as well. Therefore, in the present study we examined mothers' neural responsiveness to baby schema in a sample of mothers of toddlers and preschool aged children. We did show these mothers pictures of infants, because baby schema effects are generally strongest for infant faces (Luo et al., 2011).

Neural sensitivity to baby schema has been examined in two ways: 1) by investigating infant faces alone or in comparison to adult faces, or 2) by manipulating distinctiveness of baby schema in infant faces (increasing or decreasing infantile features such as large forehead and eyes; Glocker et al., 2009). In the current study, this baby schema manipulation approach is employed. An advantage of this manipulation is that the same infant face is used to create a version that has highly distinctive baby schema features (high baby-schematic) and a version that has less distinctive baby schema features (low baby-schematic). This controls for individual facial differences unrelated to baby schema, such as hairstyle, eye color or facial symmetry, that could otherwise confound responses to infant versus adult faces. At a behavioral level, baby schema manipulation resulting in more distinctive baby schema in infant faces has been associated with increased cuteness ratings and caregiving motivation in nonmothers (Bos et al., 2018; Glocker et al., 2009) as well as mothers (Endendijk et al., 2018). In addition, manipulated high-cute infant faces had a higher reward value than low-cute infant faces (Hahn et al., 2015a). Therefore, we expect that high baby-schematic infant faces elicit more activity in brain areas associated with reward processing than low baby-schematic infant faces.

Two neuroimaging studies so far, conducted in non-parents, have used fMRI to specifically examine effects of baby schema modulation on neural processing of infant stimuli. Glocker et al. (2009) showed that more distinctive baby schema in infant faces elicited increased activation in neural regions associated with the processing of rewards (i.e., nucleus accumbens), compared to low baby-schematic or non-manipulated infant faces. In contrast, Bos et al. (2018) found that low baby-schematic infant faces elicited more activation in the amygdala compared to high baby-schematic infant faces. Another study conducted in fathers and non-fathers compared neural processing of infant versus adult faces (Mascaro et al., 2014). This study demonstrated that in fathers infant faces (compared to adults faces) elicited greater activation in the orbitofrontal cortex (OFC), temporal parietal junction, medial frontal gyrus, superior frontal gyrus, ventromedial prefrontal cortex (vmPFC), and precuneus. The only study in parents examining baby schema manipulation with electroencephalography (EEG) observed no effects of baby schema modulation on brain activity (Endendijk et al., 2018). However, it is unlikely that EEG is able to pick up changes in neural sensitivity in specific brain areas like the amygdala or nucleus accumbens. Therefore, in the current study we used a similar paradigm in combination with fMRI to study the effect of baby schema modulation on mothers' neural responses.

The studies by Glocker et al. (2009), Bos et al. (2018), and Mascaro et al. (2014) consistently found activation in response to infant faces (across baby schema conditions) in several brain regions involved in reward processing, such as the nucleus accumbens (NAcc), putamen, and ventral tegmental area (VTA). This is not surprising, because viewing cute infants is rewarding, in the way that people are willing to expend more effort to view cute infant faces than low cute infant faces or adult faces (Hahn et al., 2013; Hahn et al., 2015a, 2015b). In addition, it has been proposed that the reward network plays an essential role in parental caregiving, because it supports approach motivation, social orienting, goal-directed behavior, social learning, and salience of infant cues (Berridge and Robinson, 1998; Feldman, 2017). In mothers, infant faces elicit fast attentional processes, as well as more controlled attentional engagement, which has been associated with activation of the parental care system and level of mothers' intrusiveness with their own children respectively (Endendijk et al., 2018).

According to Feldman (2017), the reward-motivation network of parental caregiving includes the striatum, OFC, anterior cingulate cortex (ACC), vmPFC, VTA, and amygdala. Indeed, neuroimaging studies examining infant faces alone or in comparison to adult faces, have consistently shown that viewing infant faces elicits activation in these brain regions (for review, see Luo et al., 2015). More specifically, in non-parents, increased activity to infant faces compared to adult faces was found in the ACC (Caria et al., 2012; Li et al., 2016) and OFC (Li et al., 2016). In addition, in parents, own infant faces elicited increased activity in the following areas of the reward network: the amygdala (Abraham et al., 2014; Wonch et al., 2016), putamen, (Stoeckel et al., 2014), ACC and vmPFC (Abraham et al., 2014), OFC (Wittfoth-Schardt et al., 2012), caudate (Atzil et al., 2011), NAcc (Atzil et al., 2011; Stoeckel et al., 2014), and VTA (Abraham et al., 2014; Stoeckel et al., 2014; Wittfoth-Schardt et al., 2012).

It is important to try to explain individual differences in neural processing of infant stimuli, because this might to some extent explain individual differences in infant caretaking. An important factor to examine in this regard, is individual variation in activation of the parental care system (Buckels et al., 2015; Hofer et al., 2018). The parental care system can be viewed as a motivational system: a coordinated set of affective and cognitive mechanisms, motivating parents, as well as non-parents, to provide protection and nurturance for a child (Buckels et al., 2015; George and Solomon, 2008). Several cues can activate the caregiving system, such as cues that signal danger, stress, or discomfort in a child (e.g., crying; George and Solomon, 2008), or child cues that are affectively rewarding (e.g., smiling, cute infant face; Buckels et al., 2015). When the parental care system becomes activated, this is thought to elicit protection, caretaking, parenting, and disciplining behaviors (Bowlby, 1988). Indeed, variation in activation of the parental care system was found to be associated with parents' restrictiveness, involvement, and harsh responses to child misbehavior

(Buckels et al., 2015).

It seems likely that activation of the parental care system is associated with other important parental behaviors, such as sensitivity (i.e., ability to interpret and respond to child's signals appropriately and promptly), intrusiveness (i.e., behavior that is overdirecting, overstimulating, or interfering in the child's activities), and parent-child synchrony (i.e., coordination of physiological and behavioral processes between parent and child), as well. Yet, there are only a few studies that link parents' neural responses to infant faces to actual parenting behavior, even though observations of actual parenting present a more objective and ecologically valid way to assess parenting than self-reports. One study found no significant associations between foster mothers' neural responses (P3 event-related potential; ERP) to infant faces and affective involvement with their foster child (Bick et al., 2013). Another study demonstrated that a larger difference in neural responses (N170 ERP) to emotional versus neutral faces was related to higher maternal sensitivity (Bernard et al., 2015). In addition, increased attentional engagement with infant faces (as reflected by LPP ERP) was associated with more intrusiveness of a mother with her own child during interaction (Endendijk et al., 2018), whereas in maltreated mothers lower attentional bias to infant faces was associated with lower levels of mother-infant dyadic reciprocity (Thompson-Booth et al., 2019). Furthermore, particularly in socioeconomic disadvantaged mothers, a heightened amygdala response to negative infant faces was associated with high maternal intrusive behaviors (Kim et al., 2017). In contrast, in mothers exposed to childhood maltreatment higher amygdala activation to infant faces was associated with increased maternal sensitivity, whereas in non-maltreated mothers the association was in the opposite direction (Olsavsky et al., 2019). Last, mother-infant synchrony appeared to be related to neural responses to infant cues in reward networks and closer connectivity between reward networks and brain areas involved with theory of mind and empathy (Atzil et al., 2011). The inconsistent pattern of results from this body of literature warrants more research on the association between parents' neural responses to infant faces and parenting behaviors.

Recently, it has been discovered that two distinct factors underlie parental caregiving motivation, i.e., protection and nurturance (Hofer et al., 2018). Protection refers to the motivation to protect infants from harm, whereas nurturance refers to a tendency to view infants as affectively rewarding and respond to them in a supportive, tender and physically caring way (Hofer et al., 2018). Nurturance is likely to be most relevant to explain variation in neural processing of infant stimuli, because it has been associated with sensitivity for infant cuteness, whereas protection has been associated with restrictive parenting practices (Hofer et al., 2018). In non-parents, higher self-reported nurturance was indeed related to increased neural responses to infant faces in several brain regions involved in reward and salience processing, i.e., insula, ACC, and putamen (Bos et al., 2018). However, associations with protection were not observed. Whether a similar distinction between nurturance and protection can be found in parents is not yet known. Studying parents' neural responses to infant cues in association with nurturance *as well as* protection might shed light on whether the parental care motivational system can be characterized by two separate motivational systems with distinct physiological bases.

Therefore, the current fMRI study examined mothers' neural responses to infant faces varying in distinctiveness of baby schema, and their association with the nurturance and protection aspects of the maternal care motivational system. First, we hypothesized that infant faces with more distinctive baby schema would increase neural activation of reward areas including the VTA, striatum (caudate, putamen, NAcc), amygdala, ACC, OFC, and vmPFC. Second, we hypothesized that these effects were associated with variation in mothers' nurturance and not with variation in mothers' motivation to protect children. The focus of our analyses was on the neural reward network of parental caregiving. Yet, the insula were also included in our analyses, because several studies have demonstrated the importance of this region for parental caretaking motivation and parents' responses to infant faces (Abraham et al., 2014; Atzil et al., 2011; Bos et al., 2018; Leibenluft et al., 2004; Mascaro et al., 2014; Strathearn et al., 2008). This study could be considered a preliminary study, as this is the first fMRI study examining the neural underpinnings of the baby schema effect in a small sample of mothers.

2. Materials and methods

2.1. Participants

A total number of 23 right-handed mothers with one or more young children (infant, toddler, preschool age), were recruited via the university website, parenting websites, and leaflets handed out in child-care centers. Participants had no history of psychological, neurological, or endocrine abnormalities. Participants were not pregnant and did not use psychotropic medication. Another inclusion criterium was that participants did not present (sub)clinical symptoms of psychopathology on the day of testing (mean score below 2 on the 5-point scale of the Brief Symptom Inventory 18; Derogatis, 2000), in order to reduce the confounding influence of (sub)clinical symptoms on the neural processing of infant stimuli. See Table 1 for the demographic characteristics of the mothers and children. Although our sample size was relatively small, previous small-scale fMRI studies using a similar baby schema manipulation as in the current study, showed that a sample size of at least 16 was sufficient to detect moderate to large effects (Bos et al., 2018; Glocker et al., 2009).

2.2. Procedure

Scanning sessions were scheduled within 5–10 days following the start of menstruation to exclude confounding related to hormonal changes within the cycle. Participants were informed not to drink alcohol or use drugs 24 hours prior to study participation. Before the scan session participants were screened for MRI contra-indications, and alcohol and drug use, and they were given brief explanations of the task. All participants gave written informed consent. Next, participants were screened using a metal detector, and were instructed to position themselves on the scanner bed as comfortable as possible and to try to relax.

Table 1
Demographic characteristics of sample.

	M(*SD*)	Range
Mothers' age (yrs)	37.13 (5.29)	27–45
% highly educated[a]	91%	
% Dutch-Caucasian ethnicity	96%	
Marital status		
Married/registered partnership	64%	
Cohabiting	18%	
Single parent	18%	
Number of children		
1	22%	
2	74%	
3	4%	
Sibling gender composition		
Boys only	44%	
Girls only	22%	
Boy(s) & girl(s)	35%	
Age child 1 (yrs)	6.00 (2.22)	3–10
Age child 2 (yrs)	3.83 (2.07)	1–7
Age child 3 (yrs)	5	5
% mothers with a child aged …		
0-1	4%	
2-3	35%	
4-5	74%	
>5	44%	
Psychopathology symptoms[b]	0.23 (0.23)	0–0.89

[a] Higher vocational or university level.
[b] Assessed with the Brief Symptom Inventory (BSI-18) on 5-point scale (0–4).

Head movement was minimized by foam pads, which were placed between the radiofrequency (RF)-coil and participant's head. Instructions and task images were displayed on an MRI-compatible monitor positioned at the head end of the scanner visible via an angled mirror attached to the coil. Participants received a button box in their right hand to rate the cuteness of the infant faces. Further instructions during the scan session were given by intercom. In the scanner, participants took part in the infant face task (see below). After the scan session participants were asked to complete an online version of the parental care and tenderness (PCAT) questionnaire (Buckels et al., 2015). Participants received financial compensation (€20) for their participation. The study protocol was approved by the ethics committee of the University Medical Centre Utrecht and in accordance with the latest declaration of Helsinki.

2.3. Measures

2.3.1. Infant face task

The same infant face task was used as in Bos et al. (2018). Mothers were presented with infant faces varying in distinctiveness of baby schema. The stimuli consisted of 9 different pictures of infant faces (which comprised the normal condition), which were manipulated to create additional low-baby-schematic and high-baby-schematic conditions of the same face yielding three conditions with a total of 27 stimuli (Borgi et al., 2014). For more detailed information on the stimuli see Appendix A. The 27 stimuli were presented for 3 s in random order twice for a more robust BOLD signal. This resulted in a presentation of 54 stimuli throughout the scanning session, 18 in each condition. Between the stimuli, there was a variable intertrial interval that averaged 5.5 s (min, 3.5; max, 7.5 s) during which a fixation cross was presented (total task length: 460s). Participants were instructed to carefully look at the stimuli and, after the offset of the face, use the button box in their right hand to rate on a 3-point rating scale whether the presented face was 'not very cute', 'cute', or 'very cute' (similar to Glocker et al., 2009). Use of 3-point rating scales is common practice in previous fMRI research (Bos et al., 2018; Jacques et al., 2010; Rasch et al., 2010). Cuteness ratings correlated highly between the first and second presentation of the same infant face ($r = 0.90$, $p < .001$). When positioned in the scanner, and directly before the task started, participants received instructions and performed five practice trials. Stimulus presentation, timing, and measurement of behavioral response time and accuracy were controlled by E-Prime (v 2.0) software (Schneider et al., 2002).

2.3.2. Parental care system questionnaire

The PCAT questionnaire (Buckels et al., 2015) was used to calculate the nurturance scale (PCAT-n) and the protection scale (PCAT-p) based on Hofer et al. (2018). The PCAT measures parental care motivation that consists of the conceptually separate constructs nurturance (example item: "Babies melt my heart") and protection (example item: "I would hurt anyone who was a threat to a child"). The questionnaire assesses the presence of emotions, cognitions, and actions that facilitate protection and nurturance of children, including a positive attitude towards children (liking), willingness to take care of children and protect them from harm, and the tendency to experience tenderness across a variety of situations involving children. In the validation study Cronbach's α of the PCAT-n and PCAt-p was respectively 0.88 and 0.90 (Hofer et al., 2018). For the current sample we obtained a Cronbach's α's of 0.68 and 0.61 for respectively the PCAT-n and PCAT-p. The PCAT was completed digitally using Limesurvey. Items were completed on 5-point scales (1 = *strongly disagree*, 5 = *strongly agree,* or 1 = *no tenderness at all*, 5 = *a lot of tenderness*).

2.4. Analyses

For the statistical analyses of the data on the cuteness ratings and parental care motivation, SPSS 23 (IBM analytics) was used with a significance level of $\alpha = 0.05$.

2.4.1. Cuteness ratings and parental care motivation

Mothers' cuteness ratings (not very cute: 1, cute: 2, very cute: 3) of the infant faces, as well as reaction times, were averaged per condition and checked for outliers and normality. Reaction times below 200 ms ($n = 7$ trials) were removed from the data to eliminate impulsive or unintentional button presses. Following Hahn et al., 2015a, 2015b, we calculated a *baby schema sensitivity score*, by subtracting the ratings mothers gave to the low-baby-schematic versions of infant faces from the ratings they gave to the high-baby-schematic versions. Higher scores indicate that distinctiveness of baby schema had a greater effect on ratings and that mothers were more sensitive at a behavioral level to variation in baby schema distinctiveness. We performed an ANOVA with baby schema condition as within-subjects factor to examine differences in mothers' ratings of high-baby-schematic, normal, and low-baby-schematic infants. We then added the PCAT-n as covariate to this ANOVA to test whether the maternal nurturance affected mothers' cuteness ratings. We also computed correlations between the cuteness ratings and parental care motivation.

2.4.2. fMRI data

Scanning was performed on a 3 T Philips Achieva MRI scanner (Philips Medical Systems, Best, The Netherlands). Before the functional scans, a high resolution anatomical T1-weighted scan with the following parameters was obtained for co-registration and normalization purposes: 3.8 ms echo time, 8.4 ms repetition time, 288 × 288 × 175 mm field of view, 175 sagittal slices, flip angle of 8.0°, voxelsize 1.0 mm isotropic. Blood oxygen level dependent (BOLD-) response was measured with functional T2*-weighted axial whole-brain images, of which 490 were obtained throughout the task. The 2D-EPI-SENSE sequence had the following parameters: echo time 24 ms, repetition time 1.01s, 220 × 127.5 × 220 mm field of view, 51 slices, flip angle of 65°, voxelsize 2.5 mm isotropic, SENSE-factor R = 3.0 (anterior-posterior).

Preprocessing and subsequent analyses were performed with SPM12 (http://www.fil.ion.ucl.ac.uk/spm). Functional scans were realigned after which the anatomical scan was then co-registered to the mean functional scan. Subsequently, using unified segmentation, the structural scan was segmented and normalization parameters were estimated. Using these normalization parameters, all volumes were normalized to a standard brain template (MNI) and were resliced at 2 mm isotropic voxel size. Smoothing with a 6 mm full width at half maximum Gaussian kernel was applied to the normalized functional volumes. Next, a general linear model (GLM) was applied to the data to investigate the effects of stimulus conditions. Neural responses to the infant stimuli were modeled using a 3 s boxcar function convolved with a hemodynamic response function (hrf) as implemented in the SPM12 software. Additional regressors of no interest which are entered into the analyses to reduce unexplained variance in the data include the six realignment parameters (movement in the X-,Y-,Z-direction, pitch, roll, and yaw), a discrete cosine transform high-pass filter with a cutoff of 128 s and an hrf-convolved onset of the button press by which the participant rated the stimuli (to guarantee attention of the participants to the stimuli). We further checked for excessive moment (above 2 mm in the X-, Y-, Z-direction). None of the participants had to be excluded based on this criterium.

The contrast maps of the different baby schema conditions *vs.* baseline were entered in a second-level factorial ANOVA, with baby schema condition (low, normal, high) as within-subjects factor. Comparative dependent *t*-tests were performed to investigate the (de) activations of all stimuli *vs.* rest. *F*-tests were conducted for the effect of baby schema conditions. To control for multiple comparisons in the whole-brain analyses a voxel-wise threshold was set at $p < .05$ [family-wise error (FWE) corrected, k = 0 voxels]. For studies with small sample sizes ($N < 100$) it is recommended to specifically focus on a priori

regions of interest, to reduce the risk of type II error (Carter et al., 2016). Therefore, small volume corrections (SVC; $p < .05$ FWE corrected, k = 0 voxels) were applied for the predefined (independent) bilateral regions of the interest (ROIs): the amygdala, putamen, caudate, insula, and ACC, as based on the automated anatomical labeling (AAL) template (Tzourio-Mazoyer et al., 2002). Such independent ROI analysis based on anatomical maps is highly conservative, because it is biased towards the null hypothesis (Poldrack and Mumford, 2009). The OFC was predefined based on the anatomy template (Eickhoff et al., 2007). The VTA, NAcc, vmPFC are not included in these templates as separate masks and were therefore derived from previous empirical papers. The mask for the VTA was based on Groppe et al. (2013) and consists of 2 spheres of 10 mm radius around MNI coordinates ±9, −18, −18. The bilateral mask for the NAcc was obtained from Montoya et al. (2014). The mask for vmPFC was consisted of a 10 mm sphere around MNI coordinates −1, 49, −5 (based on Abraham et al., 2016). Contrast maps of the second-level analyses are publicly available in Neurovault (via the following link: https://neurovault.org/collections/YEMYCGRM/).

2.4.3. Associations between brain activity, cuteness rating and parental care motivation

To investigate the effect of the PCAT-n on the neural responses toward infant faces, we added participants'scores on the PCAT-n as a covariate to the factorial whole brain analysis. As a sensitivity analysis, we also checked whether either PCAT-p, baby schema sensitivity, or child age were a significant covariate in the factorial whole brain analysis. Finally, for all the predefined anatomical ROIs that showed significant associations with PCAT-n in the whole brain analyses, we extracted percent signal change using MarsBaR (Brett et al., 2002) to further specify and visualize the effects with correlational analyses. We also ran exploratory correlational analyses to investigate associations between maternal nurturance and neural responses to infant faces. These correlations were only computed for the ROIs for which significant neural responses to infant faces were found.

3. Results

3.1. Cuteness ratings and parental care motivation

Table 2 shows descriptive statistics and correlations for cuteness ratings in the infant face task and parenting care motivation assessed with the PCAT. Two mothers failed to provide cuteness ratings during the infant face task, due to unknown reasons. These mothers could therefore not be included in analyses based on the behavioral ratings. No outliers were detected and data approached normality. Mothers rated high-baby-schematic and normal infant faces as significantly cuter than low-baby-schematic infant faces (condition effect: $F(2, 40) = 63.57$, $p < .001$, *partial* $\eta^2 = 0.76$; contrast high/low: $t(20) = 8.42$, 95% CI [0.34; 0.57], $p < .001$; contrast normal/low: $t(20) = 12.52$, 95% CI [0.44; 0.61], $p < .001$). No differences were found in cuteness ratings between high-baby-schematic and normal infant faces, $t(20) = -1.26$, 95% CI [-0.18; 0.05], $p = .22$. Mothers' RTs (overall $M = 677.82$ ms, $SD = 161.79$) to rate the infants' cuteness were not different between the different stimuli conditions ($F(2, 40) = 0.47$, $p = .63$, *partial* $\eta^2 = 0.02$). There was no significant interaction between baby-schema condition and maternal nurturance (PCAT-n) ($F(2,38) = 0.57$, $p = .57$, *partial* $\eta^2 = 0.03$). Cuteness ratings were strongly correlated across high-baby-schematic, low-baby-schematic, and normal conditions. Higher maternal nurturance was specifically correlated with higher cuteness ratings of low-baby-schematic infant faces. Maternal protection was not correlated with cuteness ratings of the infant faces. Baby schema sensitivity was specifically correlated with higher cuteness ratings of high-baby-schematic infant faces.

Table 2
Descriptive statistics and correlations for cuteness ratings and parental care motivation.

	1.	2.	3.	4.	5.	*M* (*SD*)
1. Cuteness High						2.15 (0.37)
2. Cuteness Normal	.74**					2.22 (0.30)
3. Cuteness Low	.75**	.82**				1.69 (0.33)
4. Sensitivity to Baby Schema	.49**	.01	-.21			0.46 (0.25)
5. Nurturance (PCAT-n)	.37	.36	.50*	-.11		4.12 (0.53)
6. Protection (PCAT-p)	.26	.18	.29	.09	.51*	3.49 (0.77)

Note. Cuteness ratings were assessed in the fMRI infant face task. Maternal nurturance and protection were assessed with a self-report questionnaire (PCAT).
*$p < .05$; **$p < .01$.

3.2. Imaging data: neural responses to baby schema and infant faces

Table 3 and Fig. 1 display the brain regions that became activated in response to infant faces, with maternal nurturance included as a covariate (neural responses to baby schema and infant faces were nearly identical without the inclusion of maternal nurturance). No significant effects of baby-schema condition on brain activity were found. Because there were no significant differences in brain activity between the different baby schema conditions, we decided to also test the contrast 'Infant faces (collapsed across baby schema conditions) vs. rest (fixation cross)'. Whole brain analyses on all participants showed widespread activation across all infant stimuli *vs.* rest, including bilateral visual cortices, hippocampus, sensory-motor areas, parietal and frontal cortices. Of the ROIs, only the insula showed significant activation levels, whereas no activation was observed for the VTA, caudate, putamen, NAcc, amygdala, ACC, OFC, and vmPFC.

3.3. Associations between brain activity, cuteness ratings and parental care motivation

The bottom part of Table 3 displays the brain regions that became activated in response to infant faces and correlated significantly with maternal nurturance (PCAT-n). Higher scores on the PCAT-n were significantly related with increased neural activation toward all infant stimuli in several regions in the bilateral visual cortex, the VTA, the putamen, and the amygdala. Sensitivity analyses with PCAT-p or behavioral baby-schema sensitivity as a covariate, showed that neither PCAT-p nor baby-schema sensitivity were significantly related with neural responses to infant faces. The age of the mothers' own children was unrelated to neural responses to infant faces.

To test the robustness of the effects of the PCAT-n, extracted values from the significant ROIs (putamen, amygdala, VTA) were entered in correlational analyses with the PCAT-n. There were moderate-to-strong significant positive correlations between the PCAT-n and activation of the putamen (Left-putamen: $r = .58$, 95% CI [0.22; 0.80], $p = .004$; Right-putamen: $r = 0.47$, 95% CI [0.07; 0.74], $p = .022$; Fig. 2a) and amygdala (Left-amygdala: $r = 0.53$, 95% CI [0.15; 0.77], $p = .01$; Right-amygdala: $r = 0.58$, 95% CI [0.22; 0.80], $p = .004$; Fig. 2b) towards all infant faces. Activation in the VTA toward all infant faces was not significantly correlated with the PCAT-n ($r = 0.17$, 95% CI [-0.26; 0.54], $p = .43$).

We checked whether associations between PCAT-n and activation in the amygdala and putamen were the same across baby-schema conditions. For the putamen, no significant differences in the strength of the correlations between the baby schema conditions were found (high: $r = 0.41$, 95% CI [0.00; 0.70], $p = .052$; normal: $r = 0.52$, 95% CI [0.14; 0.77], $p = .01$; low: $r = 0.59$, 95% CI [0.23; 0.81], $p = .003$; difference: $zs < 1.31$, $ps > .10$, calculated via psychometrica.de/correlation;

Table 3
Peak T- and F-values, p-values, cluster sizes, and MNI coordinates for significantly activated voxels in analysis with maternal nurturance (PCAT-n) as covariate.

Experimental effect		Peak voxel location			*t/F*-value	Cluster size	*p*
Region		X	Y	z		voxels	
Full factorial							
F-test: baby-schema condition[1]							NS
T-test: stimuli > rest (+)							
Middle occipital gyrus	R	28	−88	4	19.60	3326	0.0000*
Inferior occipital gyrus	R	36	−88	−4	17.28	s.c.	0.0000*
		36	−84	−12	16.82	s.c.	0.0000*
Calcarine gyrus	L	−14	−94	−10	17.16	2936	0.0000*
Inferior occipital gyrus	L	−22	−88	−10	16.47	s.c.	0.0000*
		−34	−86	−12	15.83	s.c.	0.0000*
Supplementary motor area	R	8	10	48	10.21	1114	0.0000*
	L	−6	8	46	9.44	s.c.	0.0000*
		−4	−6	64	8.39	s.c.	0.0000*
Precentral gyrus	R	46	4	32	9.23	432	0.0000*
Superior parietal lobe	R	30	−62	52	8.51	449	0.0000*
Inferior parietal lobe	R	30	−54	46	7.18	s.c.	0.0001*
Superior occipital gyrus	R	24	−62	42	6.55	s.c.	0.0005*
Precentral gyrus	L	−46	4	34	8.22	286	0.0000*
		−54	6	32	6.96	s.c.	0.0001*
Middle occipital gyrus	R	30	−72	26	7.84	99	0.0000*
Insula	R	36	22	−2	7.84	168	0.0000*
Inferior parietal lobe	L	−52	−24	40	7.76	316	0.0000*
		−42	−42	42	6.43	s.c.	0.0008*
		−48	−34	44	6.31	s.c.	0.0012*
Precentral gyrus	L	−46	−6	52	7.75	457	0.0000*
		−38	−8	60	7.17	s.c.	0.0001*
		−26	−10	52	6.70	s.c.	0.0003*
Superior parietal lobe	L	−24	−72	50	7.69	485	0.0000*
		−22	−66	44	7.58	s.c.	0.0000*
		−18	−68	58	7.58	s.c.	0.0000*
Medial frontal cortex	R	50	38	18	7.14	159	0.0001*
Pars triangularis	R	44	28	16	6.48	s.c.	0.0007*
		54	30	22	6.28	s.c.	0.0014*
Insula	L	−34	20	−2	6.64	96	0.0004*
Hippocampus	R	20	−32	−4	5.75	6	0.0084*
Superior frontal cortex	R	34	−4	62	5.71	4	0.0097*
Medial frontal cortex	R	34	−4	52	5.53	5	0.0176*
Superior frontal cortex	L	−24	−2	68	5.47	4	0.0216*
Cerebellum (crus1)	L	−8	−76	−26	5.34	2	0.0327*
Superior frontal cortex	L	−24	−10	70	5.33	1	0.0344*
Medial frontal cortex	R	46	−2	52	5.27	2	0.0419*
T-test: positive effect of PCAT-n							
Middle occipital gyrus	R	38	−74	4	6.51	23	0.001*
Middle occipital gyrus	R	32	−84	0	6.26	15	0.001*
Fusiform gyrus	L	−40	−76	−18	6.03	7	0.003*
Calcarine gyrus	L	−6	−96	−4	5.77	4	0.008*
Inferior occipital gyrus	L	−44	−80	−10	5.55	2	0.016*
VTA	R	18	−22	−16	3.57	2	0.028**
Putamen	L	−20	2	4	4.38	64	0.011**
Amygdala	R	28	−4	−12	4.09	7	0.007**

Note. R, right; L, left; s.c., same cluster as above; NS, non-significant; *whole brain FWE corrected at cluster level, **small volume FWE corrected at cluster level. [1] The baby schema condition effect was not significant for the contrast with all three conditions included (F-test condition), nor for the contrast high vs. low baby schema (T-test), or the contrast normal vs. low baby schema (T-test).

dependent samples). For the amygdala, there were also no significant differences in the strength of the correlations between the baby schema conditions (high: $r = 0.44$, 95% CI [0.03; 0.72], $p = .036$; normal: $r = 0.39$, 95% CI [-0.03; 0.69], $p = .069$; low: $r = 0.65$, 95% CI [0.32; 0.84], $p = .001$; difference: $zs < 1.42$. $ps > .08$). Results for all correlations were the same whether we controlled for background characteristics from Table 1 or not.

4. Discussion

This small-sample fMRI study examined mothers' neural responses to infant faces varying in distinctiveness of baby schema. We found that infant faces elicited widespread activation in bilateral visual cortices, the hippocampus, sensory-motor areas, parietal and frontal cortices, and the insula compared to rest. The kind and extent of activation was not modulated by the distinctiveness of baby schema in the infant faces. We also examined how mothers' neural responses to infant faces were associated with maternal tendencies to be nurturant and protective with children (i.e., aspects of maternal care motivation). Higher self-reported maternal nurturance, but not protection, was related to increased neural responses to infant faces in the putamen and amygdala.

With regard to our regions of interest, the activation we found in the insula in response to infant faces could be linked to its role in social-emotional processing, empathy for others, and salience processing (for a review, see Uddin et al., 2017). Previous research with parents also found increased insular activity to infant faces, particularly to faces of parents' own infants (Abraham et al., 2014; Atzil et al., 2011; Leibenluft et al., 2004; Mascaro et al., 2014; Strathearn et al., 2008). The increased activity in the amygdala and putamen, especially in nurturant mothers, could be an indication of reward or motivational salience processing of infant faces (Cunningham and Brosch, 2012; Feldman, 2017). Indeed, studies found increased amygdala and striatal responses to visual cues of parents' own infants (Abraham et al., 2014; Stoeckel et al., 2014; Strathearn et al., 2008; Wonch et al., 2016). Animal studies of mothering also demonstrated the importance of the amygdala for the expression of voluntary non-aggressive maternal responses such as pup licking and retrieval, and the importance of dopamine release in the striatum for normal mothering (Lonstein et al., 2015).

Unexpectedly, we found no evidence that distinctiveness of baby schema in infant faces modulated mothers' neural responses to infants, whereas the baby schema manipulation had shown clear differences in mothers' ratings of infant cuteness. Apparently, even though mothers could objectively and consciously detect differences in baby schema between infant faces, our experimental paradigm might not have been sensitive enough to detect the neural correlates of this differential cuteness rating by the mothers. This might be because of the lower number of infant face stimuli used, compared to previous fMRI research using a similar task (Glocker et al., 2009). It is also possible that more subtle variation in the neural correlates of the baby schema effect in mothers were not tapped with the parental care motivation measures used in the current study. It is unlikely that the cuteness manipulation was too subtle to elicit differential neural responses, because mothers clearly rated high- and normal baby-schematic infants as cuter than

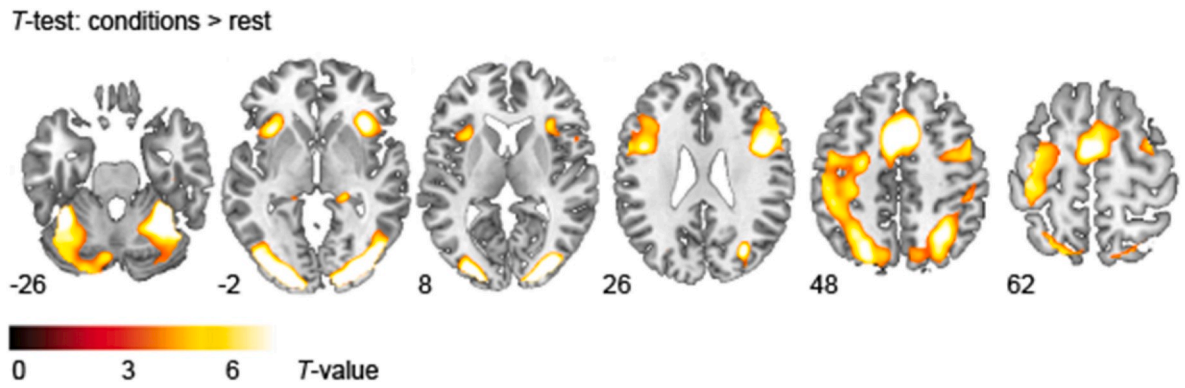

Fig. 1. Axial slices with corresponding Y-coordinates (MNI) from the T-map of neural activation of all infant faces vs. rest overlaid onto a standard anatomical template. Note. Accompanying statistics are described in the text. All statistical maps are thresholded at p = .001 uncorrected, for illustration purposes only.

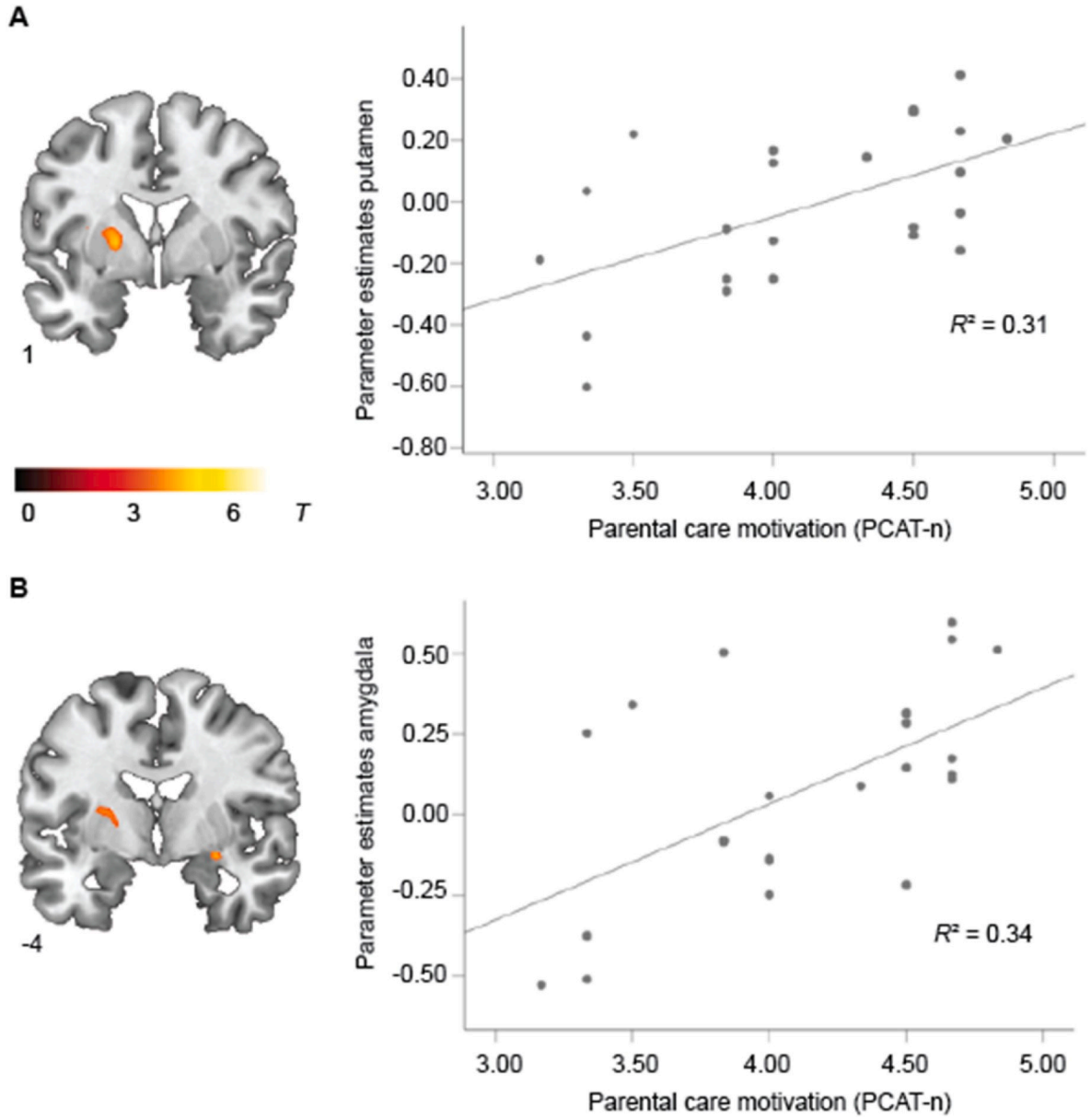

Fig. 2. Associations Between Maternal Care Motivation with Neural Activation Toward Infant Faces Versus Rest in the Putamen (A) and the Amygdala (B). Note. Figure depicts coronal slices with corresponding X-coordinates (MNI) from the T-map of neural activation toward all infant faces associated with parental care motivation. Significant activation is found in the putamen (left) and amygdala (right). Accompanying statistics are described in the text. All statistical maps are thresholded at p = .001 uncorrected, for illustration purposes only.

low-baby-schematic infants.

Important might be that no differences were found in cuteness ratings between high-baby-schematic and normal infants. This finding is not in line with previous research in non-mothers in which high-baby-schematic infants were rated as cuter than normal infants (Bos et al., 2018; Glocker et al., 2009), but it is similar to research in mothers (Endendijk et al., 2018). Analyses contrasting neural responses to high versus low baby-schematic faces, or normal versus low baby-schematic faces also revealed no differences. It appears that for mothers the high baby-schematic manipulated faces might have been more 'unnatural' compared to the normal faces, because infant faces already intrinsically possess baby schema to a large extent (Hahn and Perrett, 2014). This 'unnaturalness' might have been less obvious to nonparental adults who have less experience with infants. It is also possible that parenthood might lead to basal changes in the neural parenting network not allowing for further increases in activity by high-baby-schematic infants given the high general sensitivity of the system to infant stimuli (i.e., floor effect).

In contrast to our findings, two previous studies did demonstrate a baby schema effect on non-parents' neural processing of infant faces, albeit in different brain regions and in different directions, as well as that infant faces consistently activated reward areas of the brain (VTA, putamen, amygdala, ACC, caudate; Bos et al., 2018; Glocker et al., 2009). A plausible explanation for the difference between our findings in mothers and previous findings in non-parents might be that for mothers, unfamiliar infant stimuli might be less rewarding in general than stimuli associated with their own child (Paul et al., 2019; Stoeckel et al., 2014). In particular, this might be the case for mothers who report low levels of nurturance, who might view unfamiliar infants as less affectively rewarding. Relatedly, as our measure of nurturance taps the level of activation of the parental care motivational system (Buckels et al., 2015), this finding might indicate that for mothers who report low levels of nurturance, the parental care system is not, or less, activated in response to unfamiliar infant cues.

The differences in the results found between mothers in the current study and non-parents in previous studies, might seem plausible when assuming there is an 'alloparental caregiving' network that can flexibly activate in all adults in situations where non-parents assume responsibility for infant care, versus a neural network that becomes mainly responsive to parents' own child (Feldman, 2017; Hrdy, 2009). Longitudinal neuroimaging research is necessary to examine whether brain responses to unfamiliar child stimuli indeed change across the transition into parenthood.

It should be mentioned that individual differences in neural responses to infant faces were specifically associated with maternal nurturant tendencies and not with mothers' behavioral sensitivity to baby schema (i.e., cuteness ratings), nor with mothers' motivation to protect children. Thus, increased neural responsiveness to infant faces in the amygdala and putamen might not simply reflect a heightened sensitivity to baby schema, nor does it reflect the motivation to protect children. Instead, it reflects variation in activation of the nurturance aspect of the maternal caretaking system by infant stimuli, regardless of distinctiveness of baby schema. Previous research did demonstrate the importance of distinctive baby schema for eliciting maternal tendencies (Hahn et al., 2015b; Volk and Quinsey, 2002). Further replication is needed in order to know whether distinctiveness of baby schema may or may not be important for activating the caregiving system by unfamiliar infants.

The association between nurturance and amygdala activation with infant stimuli is not surprising, considering the central role of the amygdala in the parental brain via its connections with both the reward network (e.g., VTA, Nacc, striatum) and the empathy network (e.g., ACC, insula; Feldman, 2015). The specific associations found with nurturance also provide further support for the idea that the parental care motivational system might be best characterized by two separate motivational systems (Hofer et al., 2018), that both have a distinct physiological base. It is possible that the nurturant aspect of the parental care system is primarily activated by affectively rewarding infant cues (i.e., smiles, baby schema), whereas the protection aspect is primarily activated by cues indicating that a child is in danger, distressed, or experiencing discomfort (i.e., crying, anxious emotion expression). Some direct evidence has been found that viewing happy child faces elicits activation in brain areas associated with reward processing, whereas viewing sad child faces elicits activation in brain areas associated with threat detection (Kluczniok et al., 2017).

The following limitations of this study need to be addressed. First, our sample size was relatively small, so the lack of baby schema effect in the imaging data could have been due to power issues. The small sample size could also be a possible explanation for the low Cronbach's alphas for the nurturance and protection scales of the PCAT (Yurdugül, 2008). Therefore, our findings should be considered preliminary and need to be replicated in studies with larger samples. Second, we examined mothers with children in a wide age range, including infants, toddlers, and preschool-aged children, which may have affected our results. Baby schema are most pronounced in infant faces (Hahn and Perrett, 2014), and there might be differences between mothers with older children and mothers with infants in neural sensitivity to variation in baby schema, similar to differences between parents and non-parents. However, in the current study, controlling for child age did not change our findings and age of mother's own children was also unrelated to mothers' neural responses to infant faces. Our sample was not large enough to study whether associations were moderated by child age. Future longitudinal studies could examine whether neural responses to baby schema are more important elicitors of parental caretaking for parents with infants, than for parents with older children. Such studies could also examine the developmental trajectory of processing infant/child cues during the first years of parenthood, preferably starting during or before pregnancy and continuing in the postpartum period. Next, we only examined mothers' neural responses to baby schema in relation to activation of the parental care system, and not to actual parenting behaviors with their own child. Previous EEG research demonstrated that early stages of infant face processing were associated with mothers' activation of the parental care system, whereas later stages of infant face processing were associated with the quality of the mothers actual parenting behavior with their own children (Endendijk et al., 2018). Future fMRI research could examine brain areas associated with these differential associations between face processing and parenting outcomes in both mothers and fathers to further elucidate the similarities and differences in maternal and paternal parenting networks.

To conclude, this study extends previous research examining non-parents' neural sensitivity to baby schema, by providing preliminary evidence that variation in distinctiveness of baby schema does not modulate mothers' neural responses to infant faces. In addition, unfamiliar infant faces are not necessarily rewarding to all mothers, only for mothers who report high nurturing tendencies. These findings could suggest that in parents the parental caregiving system might be activated most by their *own* infants and less by other infants, regardless of their cuteness. Such a response would be adaptive from an evolutionary viewpoint. Yet, non-parents' neural responses to unfamiliar infant faces do vary with distinctiveness of baby schema. Future research could examine how the neural responsiveness to baby schema in non-parents changes across the transition into parenthood and which factors are associated with individual differences in these changes. Such research could improve our understanding of possible changes in the affective orientation of people to infants across the transition into parenthood.

Declaration of competing interest

None.

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Appendix A. Stimuli infant face task

Of the 9 different infant faces, 4 sets of the three conditions were kindly provided by Borgi et al. (2014). The other 5 stimuli were created based on the descriptions reported in detail elsewhere using infant faces obtained from an internet search engine (Borgi et al., 2014; Glocker et al., 2009). The infants used for the stimuli were selected to depict Caucasian infants aged between 3 months and 1.5 years of age, had neutral facial expressions and were ambiguous with regard to gender. The stimuli are available upon request. To summarize, baby schema features were captured by 6 facial parameters: Absolute face width (fw) in pixels with head length fixed and 5 proportion indices: forehead length/face length (fol/fal); eye width/face width (ew/fw); nose length/head length (nl/hl); nose width/face width (nw/fw), and mouth width/face width (mw/fw). Baby schema content in each image was manipulated using the range of baby schema values (mean and SD) from a sample of unmanipulated images as a guide for the manipulation procedure. Using Photoshop, these facial parameters were manipulated in 9 infants, to produce high baby-schematic (round face, high forehead, big eyes, small nose and mouth: fw, fol/fal, ew/fw $>$ mean, nl/hl, nw/fw, mw/fw $<$ mean) and low baby-schematic (narrow face, low forehead, small eyes, big nose and mouth: fw, fol/fal, ew/fw $<$ mean, nl/hl, nw/fw, mw/fw $>$ mean) versions of each infant face. The resize tool in Photoshop was used to enlarge or reduce (in order) forehead length, nose length, face width, eye width, nose width, and mouth width; clone stamp and healing brush tools were used to adjust sections of the picture which appeared unnaturally stretched. To maintain normal facial appearance, the manipulation for each facial parameter was restricted to a z-score range of ± 2 standard deviations. Only those parameters that needed an adjustment to obtain a high- or low baby-schematic facial characteristic were manipulated.

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