



## Review article

# Processing children's faces in the parental brain: A meta-analysis of ERP studies

Elisa Vuoriainen<sup>a</sup>, Marian J. Bakermans-Kranenburg<sup>b</sup>, Rens Huffmeijer<sup>c</sup>,  
Marinus H. van IJzendoorn<sup>d</sup>, Mikko J. Peltola<sup>a,e,\*</sup>

<sup>a</sup> Human Information Processing Laboratory, Psychology, Faculty of Social Sciences, Tampere University, Finland

<sup>b</sup> Faculty of Behavioural and Movement Sciences, Educational and Family Studies, Vrije Universiteit Amsterdam, The Netherlands

<sup>c</sup> Institute of Education and Child Studies, Leiden University, The Netherlands

<sup>d</sup> Research Department of Clinical, Education and Health Psychology, Faculty of Brain Sciences, UCL, University of London, UK

<sup>e</sup> Tampere Institute for Advanced Study, Tampere University, Finland

## ARTICLE INFO

## Keywords:

ERP  
EEG  
Parenting  
Face processing  
Children  
Meta-analysis

## ABSTRACT

Event-related potentials (ERPs) are an excellent tool for investigating parental neural responses to child stimuli. Using meta-analysis, we quantified the results of available studies reporting N170 or LPP/P3 ERP responses to children's faces, targeting three questions: 1) Do parents and non-parents differ in ERP responses to child faces? 2) Are parental ERP responses larger to own vs. unfamiliar child faces? 3) Are parental ERP responses to child faces associated with indicators of parenting quality, such as observed parental sensitivity? Across 23 studies (N = 1035), key findings showed 1) larger N170 amplitudes to child faces in parents than in non-parents ( $r = 0.19$ ), 2) larger LPP/P3 responses to own vs. unfamiliar child faces in parents ( $r = 0.19$ ), and 3) positive associations between parental LPP/P3 responses to child faces and parenting quality outcomes ( $r = 0.15$ ). These results encourage further research particularly with the LPP/P3 to assess attentional-motivational processes of parenting, but also highlight the need for larger samples and more systematic assessments of associations between ERPs and parenting.

## 1. Introduction

The transition to parenthood is associated with neural and hormonal changes that may support sensitive caregiving and responsivity to infant signals. The brain undergoes multiple structural and functional changes during pregnancy and the postpartum period (Hoekzema et al., 2017; Kim et al., 2010) in brain regions relevant for parental behavior (e.g., Witteman et al., 2019). Parental sensitivity and attention to the child's signals are important for the child's social-emotional development and for the parent's ability to respond to the child's needs accurately and promptly (see Deans, 2020, for a review). Children's facial cues are especially important elicitors of parental responses (Kringelbach et al., 2016; Parsons et al., 2013). Infants' and young children's faces have distinct features that elicit attention and caregiving behavior in adults (DeBruine et al., 2016; Glocker et al., 2009; Luo et al., 2015; Thompson-Booth et al., 2014). These include large head and eyes, chubby cheeks and a small nose.

Event-related potentials (ERPs) can be used to investigate the rapid

processing of children's face stimuli at different information processing stages. An increasing number of studies have investigated ERPs to child face stimuli (see Maupin et al., 2015, for a review). Studies have reported whether parents compared to adults without children show different neural responses to child faces (Noll et al., 2012; Peltola et al., 2014), whether parental ERP responses are heightened in response to images of one's own child (Grasso et al., 2009; Kuzava and Bernard, 2018), and whether variation in parental ERP responses to child faces is associated with indicators of parenting quality, such as observed parental sensitivity (Bernard et al., 2015) or parental attachment representations (Leyh et al., 2016). These lines of research have the potential to inform about whether becoming a parent and experience in parenting the infant shapes rapid neural responses to children's faces and, crucially, whether neural responses to children's faces are meaningfully associated with parenting quality. Here, we used meta-analysis to provide the first quantitative synthesis of this emerging field.

\* Correspondence to: Human Information Processing Laboratory, Faculty of Social Sciences, Tampere University, 33014, Finland.

E-mail address: [mikko.peltola@tuni.fi](mailto:mikko.peltola@tuni.fi) (M.J. Peltola).

<https://doi.org/10.1016/j.neubiorev.2022.104604>

Received 6 October 2021; Received in revised form 22 January 2022; Accepted 6 March 2022

Available online 10 March 2022

0149-7634/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

### 1.1. Early and late stages of facial information processing

ERP studies are important for investigating the rapid information processing stages associated with face perception. Because of their excellent temporal resolution, ERPs can reveal whether parenting affects the early perceptual decoding and later processing stages involved in heightened attention allocation and sustained orienting to motivationally significant information. ERP responses are waveforms of the electroencephalograph (EEG) signal that are averaged across multiple repetitions of a stimulus (e.g., an infant face). Facial stimuli elicit a negative deflection called the N170, peaking around 170 ms after stimulus onset at temporal occipital electrode sites and this component is found to be larger for faces than other objects (Bentin et al., 1996; Eimer, 2000). The N170 reflects structural encoding of facial features (Bentin et al., 1996; Carmel and Bentin, 2002; Eimer, 2011), but can also be modulated by emotional expressions (Batty and Taylor, 2003; Hinojosa et al., 2015; Leppänen et al., 2007). The neural generators of the N170 have been traced to visual processing areas sensitive to faces, such as the fusiform gyrus (Eimer and Holmes, 2002; Gao et al., 2019). Huffmeijer et al. (2014) found the N170 to have excellent test-retest reliability across a period of 4 weeks even with a fairly small number of repetitions of the face stimuli.

Although the N170 response can be potentiated by attentional focus, its main function is related to structural encoding, i.e., the visual processing of facial features (Eimer, 2000; Holmes, Vuilleumier et al., 2003). The later processing stages are suggested to reflect more elaborative processing reflecting sustained attention to motivationally significant stimuli (Foti and Hajcak, 2008; Olofsson et al., 2008). These later ERP components include the late positive potential (LPP) and P3 (or P300), which are positive deflections of the EEG signal beginning around 300 ms after stimulus onset mainly at parietal regions (Hajcak et al., 2009; Hajcak and Foti, 2020; Polich, 2007; Schupp et al., 2000). Both P3 and LPP are affected by emotional valence, being larger for emotional compared to neutral stimuli (Cuthbert et al., 2000; Olofsson et al., 2008; Schupp et al., 2003) and this effect is enhanced when the emotional stimuli are task-relevant (Ferrari et al., 2008; Schupp et al., 2007) or when attending to arousing aspects of the stimulus (Hajcak et al., 2009). Also altering the appraisal of the stimuli can affect the response amplitude (Hajcak and Nieuwenhuis, 2006; Foti and Hajcak, 2008; Moser et al., 2006). Based on these findings, the LPP/P3 complex has been suggested to reflect both automatic increases in attention for motivationally salient stimuli and top-down cognitive processes (Hajcak et al., 2009). Here we apply the commonly used definitions of the functions of the N170 and LPP/P3 and refer to them as reflecting perceptual processing (N170) and attentional processing (LPP/P3). The LPP and P3 show good test-retest reliability, but may require a larger number of trials for reliable assessment than the N170 (Huffmeijer et al., 2014), although Moran et al. (2013) observed good consistency and split-half reliability for the LPP even with a relatively small number of trials.

There are multiple types of ERP components suitable for different experimental paradigms, but the most commonly reported ERP components in studies measuring brain responses to infant or child faces are the N170, LPP, and P3 components. Although there are differences in the specific properties of the P3 and LPP components (with the P3 associated with a more distinctive peak and the LPP a more sustained waveform), the nomenclature used in different studies does not uniformly conform to strictly separate definitions (cf. Cuthbert et al., 2000; Olofsson et al., 2008). LPP responses are commonly reported in studies with passive viewing tasks and equal presentation frequency of different stimuli, whereas P3 responses are often reported in oddball paradigms in which target stimuli are presented with lower frequency. Despite the P3 and LPP being elicited commonly under different task conditions, they cannot be simply distinguished based on the applied task paradigm, since both components are similarly potentiated by factors such as target status and emotional content of the stimuli (Hajcak and Foti, 2020).

Indeed, studies with similar task paradigms may report ERPs with different nomenclature (e.g., Bernard et al., 2018; Bick et al., 2013). Importantly, it has been argued (Bradley, 2009; Hajcak and Foti, 2020) that both components could reflect the output of neural processes evaluating the motivational significance of stimuli (i.e., the degree to which stimuli activate approach or avoidance motivation), and the shape of the ERP waveform primarily reflects task parameters such as duration and frequency of stimulus presentation. Although there is need for further investigation to determine the relationship between P3 and LPP (Hajcak and Foti, 2020) for the purposes of this meta-analysis we will primarily use the term LPP when referring to studies reporting either LPP or P3 responses.

### 1.2. Parental sensitization to infant signals

Our attention is easily drawn towards infant faces. Using a reaction time task, Thompson-Booth et al. (2014) observed that although infant faces captured attention more strongly than adult faces in both mothers and women without children, the attentional bias to infant faces was more pronounced in mothers. There are, however, only a few ERP studies investigating the effect of parenthood on child face processing at earlier structural encoding stages (N170) and at later, more elaborative processing stages (LPP). Larger N170 and LPP responses to child faces in parents as compared to adults without children could indicate increased perceptual processing and sustained attention to cues relevant to parenting, potentially due to neural and hormonal changes associated with the transition to parenthood or greater experience with children's faces. There is some indication that parental status modulates N170 and LPP responses to children's faces, but the initial findings have been inconsistent (Noll et al., 2012; Peltola et al., 2014; Proverbio et al., 2006; Weisman et al., 2012). Regarding N170, one study found a larger N170 response to children's faces in parents compared to single non-parents (Weisman et al., 2012), while some studies found no such difference in N170 between mothers and nulliparous women (Noll et al., 2012; Peltola et al., 2014) or found ERP modulation by parental status only in interaction with gender (Proverbio et al., 2006). Proverbio et al. (2006) found larger N170 in mothers compared to fathers, while responses did not differ between male and female non-parents. Regarding the later processing stage, the number of available studies is small. While one study (Proverbio et al., 2006) observed larger LPP responses to child faces in parents compared to non-parents, others have found either no modulation by parental status (Peltola et al., 2014) or even smaller LPP amplitudes to unfamiliar infant faces in parents as compared to adults without children (Weisman et al., 2012).

### 1.3. Effects of face familiarity on parents' ERP responses

In parents, the perceptual and attentional brain responses may also be greater to the face of one's own child due to its greater familiarity and motivational significance. Functional magnetic resonance imaging (fMRI) studies have found that viewing one's own child's face recruits the brain's reward circuitry and emotion processing areas (Bartels and Zeki, 2004; Leibenluft et al., 2004; see Rilling, 2013, for a review). Several ERP studies have investigated parents' perceptual processing of and attention to their own child's face. Studies have in general reported no N170 modulation in parents when viewing their own child's face as opposed to another child's face (Bornstein et al., 2013; Grasso et al., 2009; Waller et al., 2015; Weisman et al., 2012). Absence of N170 modulation to the own child face is in line with previous studies that have found the N170 to be independent of the identity of faces (Bentin et al., 1996) or face familiarity (Bentin and Deouell, 2000; Eimer, 2000), suggesting that the N170 reflects categorical detection of the face configuration, instead of face identification (Bentin and Deouell, 2000; Eimer, 2000). Regarding the later processing stages, several studies have reported larger LPP responses to own child faces (Bernard et al., 2018; Grasso et al., 2009; Kuzava and Bernard, 2018; Weisman et al., 2012).

Enhanced responses at these later components could reflect increased attention allocation to these motivationally significant stimuli.

Regarding the role of face familiarity, while many studies only compared own child faces to unfamiliar child faces (Bornstein et al., 2013; Doi and Shinohara, 2012a, 2012b; Weisman et al., 2012) some studies have included a familiarization process to previously unknown child pictures to obtain a control condition of familiar children's faces, making it possible to dissociate own child and familiarity effects. The findings indicate that the enhanced LPP response to own child is not explained by a familiarity effect, since LPP responses were found to be larger to own child compared to familiar child faces (Bernard et al., 2018; Bick et al., 2013; Grasso et al., 2009; Kuzava and Bernard, 2018).

#### 1.4. ERPs associated with parenting quality

Given the importance of parental sensitivity to child signals on parent-child interaction, there is remarkably little research on the potential associations between ERPs and parenting behavior. Individual differences in ERPs to child stimuli could potentially indicate variation of parenting quality. In the present meta-analysis, we analyzed the available studies that have investigated associations between ERP responses to children's faces and indicators of parenting quality, such as observed parental sensitivity or parental attachment representations. Parental sensitivity and parental representation of attachment have been recognized as important contributors to children's socio-emotional development (Ainsworth et al., 1978; Bakermans-Kranenburg et al., 2003; Deans, 2020; Verhage et al., 2018).

There is some indication that parenting behaviors may be associated with processing of children's facial cues as measured with ERPs. However, studies have shown mixed findings regarding the direction and timing of the associations, and various indicators of parental behavior have been used. Some studies have found that larger N170 (Bernard et al., 2015) or LPP (Kuzava et al., 2019) responses to emotional infant faces were associated with greater observed maternal sensitivity. However, larger LPP responses to infant faces have also been associated with greater maternal intrusiveness (Endendijk et al., 2018). There is also some indication that maternal risk factors may be associated with ERPs to infant facial expressions. For example, mothers who had been referred to Child Protective Services (CPS) because of child neglect were found to lack similar N170 and LPP modulation to children's emotional expressions that was found in control mothers (Bernard et al., 2015; Rodrigo et al., 2011). Studies have also investigated ERP associations with parents' attachment representations, which are robustly associated with child attachment quality, partly mediated by their influence on parental sensitivity (Verhage et al., 2016). Therefore, parental attachment representations may provide important indicators of parental responses to child's signals. One small study reported larger N170 and LPP responses to infant faces in mothers with a secure compared to insecure attachment representation (Fraedrich et al., 2010). Another study found larger N170 amplitudes to negative infant expressions in insecurely attached mothers, but larger LPP responses to positive and negative expressions in securely attached mothers (Leyh et al., 2016). Groh and Haydon (2018) observed larger LPP responses in insecurely attached compared to securely attached mothers when mothers attended to distressed expressions of their own child, but not when attending to happy expressions. Associations between ERPs and self-reported parenting quality have also been investigated. Larger N170 responses to happy and neutral infant faces were associated with greater parental certainty in understanding of their infant's mental state (Rutherford et al., 2017). In another study, larger LPP responses to own infant faces were associated with more positive evaluations of the mother-child relationship (Grasso et al., 2009). Other studies measuring ERPs to unfamiliar infant faces found no associations between LPP responses and mother-child relationship measures (Dudek et al., 2020; Rutherford et al., 2017).

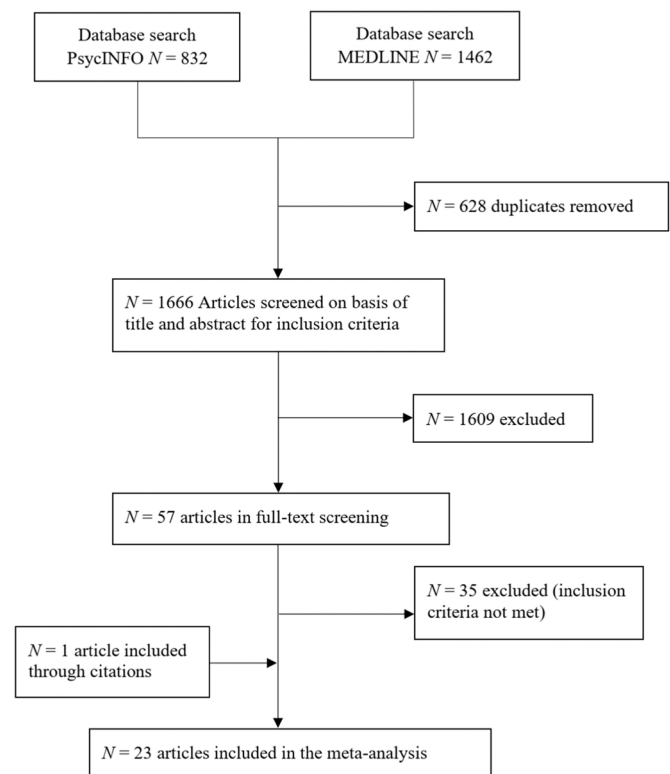


Fig. 1. Flowchart of the study selection process.

#### 1.5. Aims of the meta-analysis

One previous meta-analysis has been conducted on adults' ERP responses to children's facial expressions by Kuzava et al. (2020). While that study examined also the effect of parental status on ERP responses, it did not specifically focus on parental ERP responses. The results showed that parental status moderated the difference in N170 responses to crying versus neutral faces. Larger N170 responses in parents to crying than neutral facial expressions were found while no such difference was found in non-parents. In the current meta-analysis, we aim to synthesize the available literature focusing specifically on *parental* ERP responses to children's faces to elucidate whether child faces in general and own child face in particular elicit larger perceptual and attentional brain responses in parents than in non-parents. Crucially, the current meta-analysis will also contribute to our understanding of whether and how parenting quality is associated with parental ERP responses to own and unfamiliar children's faces. We will examine N170 and LPP responses to child faces as these components are most commonly reported. First, we will examine whether ERPs to pictures of child faces differ between parents and non-parents, potentially reflecting greater sensitization to child faces in parents. The second analysis will focus on whether parental ERP responses are heightened in response to images of one's own child, possibly due to their greater motivational significance. Finally, as a critical step toward elucidating the behavioral implications of the ERP responses to child faces, we analyze whether ERPs to child faces correlate with indicators of parenting quality.

## 2. Method

### 2.1. Literature search

Fig. 1 presents a flowchart of the study selection process. As the first step, PsycINFO and MEDLINE databases were searched by two authors for English language journal articles published before May 2021, which included the words "parent\*" or "caregiver\*" or "mother\*" or "father\*"

**Table 1**  
Summary of study characteristics.

Study	Type of meta-analysis	N	Participant mean age (years)	Child mean age (months)	Stimulus emotions	Task type	Stimulus presentation time and order	ERP components and time windows	Reference electrodes	Parenting quality indicator
Bernard et al. (2015)	PQ	70	31.6	59.24	Distress, happy, neutral	Emotion categorization	2000 ms; random	N170: (140–180 ms), LPP (300–650 ms)	N170: average LPP: mastoids	Observed sensitivity
Bernard et al. (2018)	OU, PQ	73	32.26	59.94	Neutral	Passive viewing	2000 ms; random	LPP (300–650 ms)	Mastoids	Observed sensitivity
Bick et al. (2013)	OU, PQ	33	42.1	8.5	Neutral	Passive viewing	2000 ms; random	P3 (300–650 ms)	Mastoids	Observed delight during interaction
Bornstein et al. (2013)	OU	22	32.06	4.5	Neutral	Passive viewing	500 ms; random	N170 <sup>a</sup> (100–230 ms); LPP <sup>a</sup> (580–650 ms)	Average	
Doi and Shinohara (2012a)	OU	16	31.7	12.3	Distress, happy, neutral	Detect target faces	1000 ms; oddball	N170 (140–220 ms), P300 (250–800 ms)	Average	
Doi and Shinohara (2012b)	OU	16	33.7	67	Neutral	Detect target faces	1000 ms; oddball	N170 (120–180 ms), P300 (300–800 ms)	Average	
Dudek et al. (2020)	PQ	39	30.5	3.69	Distress, happy	Passive viewing	1000 ms; random	N170 (140–200 ms), LPP (500–800 ms)	Average	Self-report (parental bonding)
Endendijk et al. (2018)	PQ	33	34.18	37.8	Neutral	Cuteness rating	2000 ms; random	N170 (150–230 ms), LPP (300–700 ms)	Average	Observed sensitivity
Fraedrich et al. (2010)	PQ	16	40.5	Not reported	Distress, happy, neutral	Detect target faces	500 ms; oddball	N170 (120–180 ms), P300 (300–600 ms)	Mastoids	Attachment (Adult Attachment Projective Picture System)
Grasso et al. (2009)	OU, PQ	28	36.61	32.4	Neutral	Passive viewing	1000 ms, random	N170 (150–185 ms), P3 (350–525 ms)	Mastoids	Interview (This is my Baby Interview)
Groh and Haydon (2018)	PQ	70	30	6	Distress, happy, neutral	Detect target faces	600 ms, oddball	P3b (300–500 ms)	Mastoids	Attachment (Attachment Script Assessment)
Kuzava and Bernard (2018)	OU	85	29.43	9	Neutral	Passive viewing	2000 ms, random	LPP (300–1000 ms)	TP9/TP10	
Kuzava et al. (2019)	PQ	86	29.48	9	Distress, happy, neutral	Emotion categorization	2000 ms, random	N170 (140–180 ms), LPP (300–600 ms)	N170: average LPP: TP9/TP10	Observed sensitivity
Leyh et al. (2016)	PQ	25	29.8	11.1	Distress, happy, neutral	Detect target faces	500 ms; oddball	N170 (120–180 ms), P3 (300–600 ms)	Average	Attachment (Adult Attachment Interview)
Lowell et al. (2021)	OU, PQ	59	29.33	8.17	Distress, happy	Passive viewing	500 ms; random	N170 (135–202 ms), P300 (250–600 ms)	Average	Attachment (Adult Attachment Interview)
Márquez et al. (2019)	PQ	20	35.5	61.2	Distress, happy, neutral	Detect target faces	1000 ms, random,	N170 (90–180 ms)	Average	Observed sensitivity
Noll et al. (2012)	PN	30	31.53	21.64	Distress, happy, neutral	Passive viewing	1500 ms, random	N170 (99–235 ms)	Average	
Peltola et al. (2014)	PN	90	27.1	7	Distress, happy, neutral	Count adult or infant faces	1000 ms, random	N170 (120–210 ms), LPP (300–450 ms)	Average	
Proverbio et al. (2006)	PN	38	33.77	32	Distress, happy, neutral	Emotion categorization	900 ms, random	N170 (140–175 ms), P300 (375–600 ms)	Linked ears	
Rodrigo et al. (2011)	PQ	28	35.1	39	Distress, happy, neutral	Emotion categorization	2000 ms, random	N170 (170–250 ms), LPP (530–700 ms)	N170: average LPP: mastoids	Neglect (Child Protective Services record)

(continued on next page)



Table 1 (continued)

Study	Type of meta-analysis	N	Participant mean age (years)	Child mean age (months)	Stimulus emotions	Task type	Stimulus presentation time and order	ERP components and time windows	Reference electrodes	Parenting quality indicator
Rutherford et al. (2017)	PQ	62	29	6	Distress, happy, neutral	Passive viewing (with occasional catch trials)	500 ms; random	N170 (129–199 ms), P300 (200–600 ms)	Average	Self-report (Parental Reflective Functioning Questionnaire)
Waller et al. (2015)	OU, PQ	24	39.8	59	Happy	Passive viewing	2000 ms, random	N170 (142–200 ms)	FCz	Attachment (Adult Attachment Projective Picture System)
Weisman et al. (2012)	OU, PN	65	25.5	6	Neutral	Detect target faces	300 ms; oddball	N170 (140–160 ms), P300 (300–500 ms)	Not reported	

NOTE:

PN = parent vs. non-parent; OU = own vs. unfamiliar; PQ = parenting quality; N = sample size in the analyses

<sup>a</sup>In the original paper, N170 and LPP were named as N/P1 and N/P600, respectively

” and “event-related potential\* ” or “ERP” or “EEG” in the title or abstract (the asterisk indicating that the search contained the word or word fragment). Using these different search terms characterizing parents ensured that the search would be able to include potential articles with diverse caregiving arrangements (e.g., same-sex or adoptive parents). After removal of duplications, the search returned 1666 articles, of which the titles, and in some cases also abstracts, were screened. Of these, 57 articles were selected for more detailed full-text screening. This screening resulted in an inclusion of 22 articles, which fulfilled the criteria of reporting either N170 or LPP ERP amplitudes or both, having parents as participants, and child faces as visual stimuli. As the second search step, a Google Scholar search for studies citing the included articles was performed, resulting in an inclusion of one more article, adding to a total of 23 independent samples ( $N = 1035$ ). The included articles provided effect size data for analyses comparing parents’ vs. non-parents’ ERP responses to child faces (N170  $k = 4$ , LPP  $k = 3$ ), parents’ ERP responses to own vs. unfamiliar child faces (N170  $k = 7$ , LPP  $k = 9$ ), and for analyses of associations between parents’ ERP responses to child faces and indicators of parenting quality (N170  $k = 11$ , LPP  $k = 13$ ). Data for the analyses of ERP and parenting quality associations included articles reporting observed parental sensitivity (e.g., Bernard et al., 2015), parental secure vs. insecure attachment representation (e.g., Leyh et al., 2016), and self-reported characteristics that are associated with parenting such as reflective functioning (e.g., Rutherford et al., 2017). Following these criteria, effect sizes representing associations between ERPs and intranasal oxytocin administration to parents (Peltola et al., 2018; Waller et al., 2015) or maternal anxiety (Malak et al., 2014) were not included in this analysis as their influence on parenting quality was not considered to be sufficiently clear. The studies varied in whether neutral or emotional (smiling and/or crying) child faces were presented as stimuli. When effect size information was available for both types of stimuli, effect sizes reflecting ERPs to emotional faces were used in the analyses given initial findings by Kuzava et al. (2020) that parents may show larger ERP responses (particularly the N170) to emotional relative to neutral child faces than non-parents. In cases where effect size information for both types of stimuli was available, we also calculated effect sizes for neutral faces, and the findings remained identical. Therefore, the analyses using effect sizes for neutral faces from those studies are not reported here. Descriptive information on all studies included in the meta-analyses is provided in Table 1.

## 2.2. Moderators

In the categorical moderation analyses, moderator subgroups with  $k < 4$  studies were excluded from the subgroup comparisons. As a

consequence, categorical moderation analyses are only reported for the parenting quality association studies. As categorical moderators, we analyzed 1) whether stimulus emotion influenced the magnitude of effect sizes by comparing effect sizes based on studies with only neutral facial expressions with effect sizes based on ERPs to emotional child faces, 2) whether the effect sizes were based on responses to own vs. unfamiliar child faces (i.e., face familiarity), 3) whether the type of task influenced effect sizes (the most common task types being passive viewing, target detection/oddball, and emotion categorization), 4) the influence of reference electrode scheme, and 5) whether the measure of parenting quality indicator moderated the magnitude of effect sizes. For the latter analysis, we contrasted studies using observational assessments with studies assessing parental attachment representations, as there were sufficient number of studies available for this comparison. Therefore, studies with self-report (Dudek et al., 2020; Rutherford et al., 2017) or interview (Grasso et al., 2009) as the parenting quality measure were excluded from these moderation analyses. The study using CPS records as an indicator of parental neglect (Rodrigo et al., 2011) was coded among the observational measures. As continuous moderators, we selected participant age and own child age to estimate their influence on ERP responses. To assess intercoder reliability, 10 studies were coded by an independent coder. The average agreement (Cohen’s  $\kappa$ ) between the coders across the categorical moderator variables was  $\kappa = 0.86$  and correlations between the continuous moderators were  $r = 1.00$ .

## 2.3. Meta-analytic procedures

For each study, the pertinent results were transformed into correlation coefficients ( $r$ ) which were used as effect size estimates. Combined effect sizes across studies (weighted by the standard errors within individual studies) and their 95% confidence intervals (CIs) were calculated using the Comprehensive Meta-Analysis (CMA) program (Borenstein et al., 2013). Significance tests of the combined effect size analyses were performed with the  $Q$ -statistic on the basis of random-effects models. The  $Q$ -statistic was also used to assess the heterogeneity of the effect sizes across studies. Categorical moderator analyses were performed by comparing differences in effect sizes between subgroups, using  $Q$ -tests with mixed-effect models. Meta-regression was used to test the influence of continuous moderators. To screen for potential outliers, Fisher’s  $Z$  scores were computed as equivalents for the effect size  $r$ , and the  $Z$  scores were then standardized and screened. No outliers (standardized  $Z$  scores  $\pm 3.29$ ; Tabachnick and Fidell, 2001) were observed in the total set of studies. For each meta-analysis with a statistically significant combined effect size, we also estimated the sample size required to detect the pertinent combined effect size (i.e., the putative true effect size) with sufficient power (i.e., .80 with a

**Table 2**  
Combined effect sizes and categorical moderators.

	<i>k</i>	<i>N</i>	<i>r</i>	95% <i>CI</i>	<i>Q-W</i>	<i>Q-B</i> <sup>a</sup>
<b>Parent vs. non-parent N170</b>						
Total	4	223	0.19 <sup>b</sup>	0.06 – 0.31	2.94	
<b>Parent vs. non-parent LPP</b>						
Total	3	193	-0.03	-0.52 – 0.48	30.59 <sup>c</sup>	
<b>Own vs. unfamiliar N170</b>						
Total	7	230	0.02	-0.03 – 0.07	4.91	
<b>Own vs. unfamiliar LPP</b>						
Total	9	397	0.19 <sup>c</sup>	0.09 – 0.29	56.72 <sup>c</sup>	
<b>Parenting quality N170</b>						
Total	11	460	0.06	-0.04 – 0.17	15.11	
Parenting measure						2.844
Observed	5	237	0.18	0.05 – 0.30	3.76	
Attachment	4	122	0.01	-0.13 – 0.15	3.53	
<b>Parenting quality LPP</b>						
Total	13	622	0.15 <sup>d</sup>	0.03 – 0.26	23.58 <sup>d</sup>	
Stimulus emotion						0.61
Emotional	9	455	0.18 <sup>b</sup>	0.05 – 0.30	14.42	
Neutral	4	167	0.06	-0.21 – 0.32	8.34 <sup>d</sup>	
Face familiarity						0.35
Own	5	263	0.10	-0.09 – 0.28	8.81	
Unfamiliar	8	359	0.17 <sup>d</sup>	0.02 – 0.32	13.86	
Parenting measure						0.006
Observed	6	323	0.14	-0.04 – 0.31	12.20 <sup>d</sup>	
Attachment	4	170	0.15	-0.12 – 0.41	9.12 <sup>d</sup>	
Reference scheme						0.06
Average	5	218	0.12	-0.09 – 0.32	9.51	
Mastoids	7	318	0.16	-0.02 – 0.32	13.79*	

*k* = number of study outcomes, *N* = total sample size, *r* = effect size, 95% *CI* = 95% confidence interval around the point estimate of the effect size, *Q-W* = a statistic testing for the homogeneity within a set of studies, *Q-B* = a moderation statistic testing for the significance of the contrast between different sets of studies.

<sup>a</sup> Subgroups with *k* < 4 were excluded from the moderator contrast

<sup>b</sup> *p* < .01

<sup>c</sup> *p* < .001

<sup>d</sup> *p* < .05

one-sided significance level of .05) by using G\*Power (Faul et al., 2007). In addition, the power values of the individual studies were calculated to estimate the median power of the included studies to detect the combined effect size. Instead of estimating sample sizes and power identically in each meta-analysis, the designs for the sample size and power estimation were matched with the characteristics of each meta-analysis. Thus, for the parent vs. non-parent meta-analysis, power analysis was based on an independent sample *t*-test. For the own vs. unfamiliar comparison, a paired sample *t*-test design was used. For the dataset of parenting quality associations, power and sample sizes were estimated based on bivariate correlations between ERP responses and the outcome.

In addition to the main analyses, we performed exploratory analyses to estimate whether the current dataset indicated any evidence of publication bias and whether the studies in general show evidential value. A funnel plot was constructed by plotting each effect size as a function of its standard error, which indicates selective reporting of positive findings if negative results with larger standard errors (i.e., smaller studies) are underrepresented as compared to positive findings with similar standard errors. Statistical asymmetry of the distribution of effect sizes was analyzed with Egger's *t*-test. Second, a *p*-curve analysis (Simonsohn et al., 2014) was used to assess whether the statistically significant results across all studies show evidential value, i.e., whether the distribution of *p* values among statistically significant results is right-skewed in an expected way, with small *p* values (e.g., *p* < .01) more prominent than larger *p*-values (e.g., *p* = .04). The funnel plot and *p*-curve analyses were conducted for all effect sizes simultaneously (i.e., instead of separately for the different types of meta-analyses) to have greater power in the analyses. Statistical information for all meta-analyses is provided in Table 2.

### 3. Results

#### 3.1. Preliminary analyses

In a funnel plot of all effect sizes (Fig. 2) the effect sizes distributed relatively evenly around the combined weighted effect size, indicating an absence of a clear publication bias in the current dataset. Statistical asymmetry was, likewise, not indicated by the Egger's *t* = 1.47, *p* = .15. In addition, the *p*-curve analysis produced a clearly right-skewed *p*-curve (Fig. 3),  $Z_{full} = -7.48$ , *p* < .0001,  $Z_{half} = -8.08$ , *p* < .0001, indicating that the published results have evidential value.

#### 3.2. Do parents and non-parents differ in ERP responses to child faces?

**3.2.1. N170.** For the N170, the analysis of the available studies (*k* = 4, *N* = 223) showed a significant combined effect size, *r* = 0.19, *CI* [.06,.31], *p* = .005, which indicated that across these studies, N170 amplitudes to child faces were larger (i.e., more negative) in parents than in non-parents (Table 3). Power analyses indicated that a sample size of 182 (i.e., 91 per group) would be required for a study to detect the combined effect size with a power of .80 in an independent samples *t*-test. Consequently, the studies included in this analysis were underpowered in relation to the combined effect size, with the median power of the studies being .36.

**3.2.2. LPP.** Across the available studies (*k* = 3, *N* = 193), no differences in LPP amplitudes to child faces were observed between parents and non-parents, *r* = -0.03, *CI* [-0.52,.48], *p* = .91.

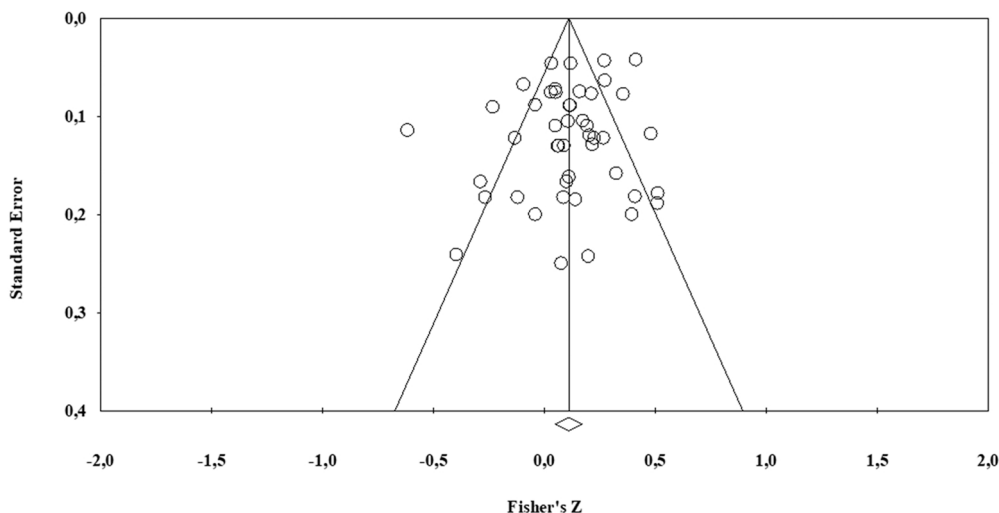


Fig. 2. Funnel plot of effect sizes and standard errors of all studies included in the current analyses.

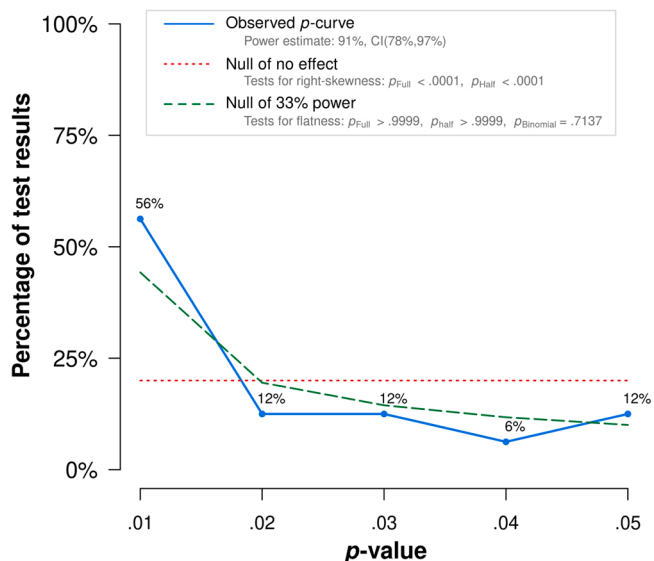


Fig. 3. *p*-curve obtained from <https://www.p-curve.com/> (version 4.06).

### 3.3. Are Parents' ERP Responses Larger to Own Child Faces than to Unfamiliar Child Faces?

3.3.1. *N170*. Within studies of parents ( $k = 7, N = 230$ ), the *N170* amplitudes did not differentiate between pictures of own child vs. unfamiliar child faces,  $r = 0.02, CI [-0.03, .07], p = .48$  (Table 4). No significant heterogeneity was observed,  $Q = 4.91, p = .56$ .

3.3.2. *LPP*. As can be observed from Table 4, *LPP* amplitudes were consistently larger to own vs. unfamiliar child faces across  $k = 9$  ( $N = 397$ ) studies,  $r = 0.19, CI [0.09, .29], p < .001$ . Heterogeneity across effect sizes was large,  $Q = 56.72, p < .001$ . In the meta-regression analyses, neither participant age,  $Q = 0.09, p = .76$ , nor child age,  $Q = 1.44, p = .23$ , moderated the effect sizes. A power analysis with a paired samples design estimated a sample size of 41 for detecting the combined effect size with .80 power. The power of the individual studies included in this dataset ranged from .45 to .98, with a median power of .63.

Table 3

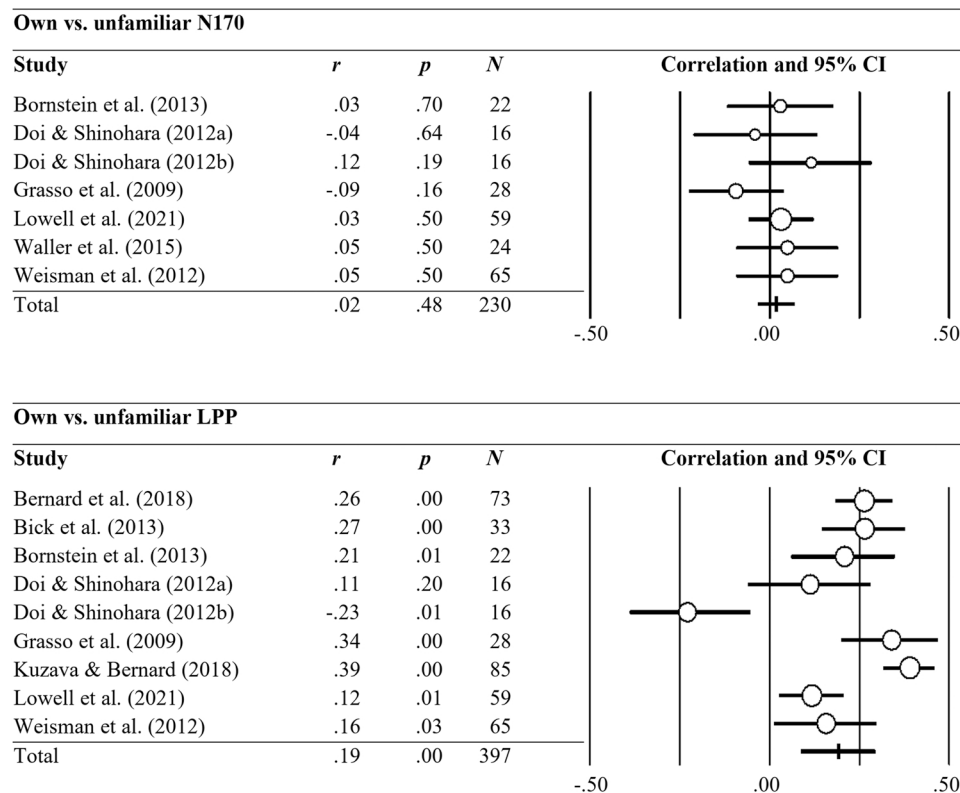
Effect sizes and forest plots for studies comparing *N170* (above) and *LPP* (below) responses to child faces in parents vs. non-parents.

Parent vs. non-parent <i>N170</i>				Correlation and 95% CI
Study	<i>r</i>	<i>p</i>	<i>N</i>	
Noll et al. (2012)	.14	.45	30	
Peltola et al. (2014)	.11	.31	90	
Proverbio et al. (2006)	.11	.50	38	
Weisman et al. (2012)	.35	.00	65	
Total	.19	.00	223	
Parent vs. non-parent <i>LPP</i>				Correlation and 95% CI
Study	<i>r</i>	<i>p</i>	<i>N</i>	
Peltola et al. (2014)	.17	.10	90	
Proverbio et al. (2006)	.31	.04	38	
Weisman et al. (2012)	-.52	.00	65	
Total	-.03	.91	193	

Noll et al. (2012); Peltola et al. (2014); Proverbio et al. (2006); Weisman et al. (2012).

**Table 4**

Effect sizes and forest plots for studies comparing N170 (above) and LPP (below) responses to own vs. unfamiliar child faces in parents.



Bornstein et al. (2013); Doi and Shinohara (2012a); Doi and Shinohara (2012b); Grasso et al. (2009); Lowell et al. (2021); Waller et al. (2015); Weisman et al. (2012); Bernard et al. (2018); Bick et al. (2013); Kuzava and Bernard (2018).

### 3.4. Are parents' ERP responses associated with indicators of parenting quality?

**3.4.1. N170.** Across 11 studies ( $N = 460$ ; Table 5), N170 amplitudes were not consistently associated with indicators of parenting quality,  $r = 0.06$ , CI  $[-0.04, .17]$ ,  $p = .24$ , and no significant heterogeneity was observed,  $Q = 15.11$ ,  $p = .13$ . Although the effect sizes appeared larger for studies with observed ( $r = 0.18$ ) than attachment measures ( $r = 0.01$ ), the moderation effect of the measure of parenting quality indicator was not significant,  $Q = 2.844$ ,  $p = .09$ .

**3.4.2. LPP.** Across 13 studies ( $N = 622$ ; Table 5), LPP amplitudes showed a significant association with indicators of parenting quality,  $r = 0.15$ , CI  $[.03, .26]$ ,  $p = .01$ , in a heterogenous set of studies,  $Q = 23.58$ ,  $p = .02$ . Thus, larger LPP amplitudes to child faces in parents were associated with more favorable parenting outcomes. While the effect sizes appeared somewhat larger in studies presenting emotional ( $r = 0.18$ ) than neutral ( $r = 0.06$ ) faces, and unfamiliar ( $r = 0.17$ ) than own ( $r = 0.10$ ) child faces, the moderation effects of stimulus emotion,  $Q = 0.61$ ,  $p = .44$ , and face familiarity,  $Q = 0.35$ ,  $p = .55$ , were not significant. The moderation effects of reference electrode scheme,  $Q = 0.06$ ,  $p = .81$ , and the measure of parenting quality indicator (observed vs. attachment measures) were not significant either,  $Q = 0.006$ ,  $p = .94$ . In the meta-regression analyses, neither participant age,  $Q = 0.18$ ,  $p = .67$ , nor child age,  $Q = 0.68$ ,  $p = .41$ , moderated the effects. The included studies were largely underpowered to detect the rather small combined effect size, with the median power of the included studies being .23. For an individual study, a sample size of 273 would be required to detect a correlation of  $r = 0.15$  with .80 power.

## 4. Discussion

A growing number of studies are investigating how the transition to parenthood impacts hormones as well as brain structure and functioning, and how such changes might support sensitive caregiving (e.g., Bakermans-Kranenburg et al., 2021; Hoekzema et al., 2017; Kim, 2016). EEG and ERP measurements are ideal tools for measuring rapid and largely automatic perceptual and attentional brain responses to child-related stimuli (Maupin et al., 2015). Therefore, the purpose of this meta-analysis was to analyze the available literature on the N170 and LPP ERP responses to children's face stimuli, focusing on three key questions: 1) Do parents and non-parents differ in their ERP responses to child faces? 2) In parents, are ERP responses larger to own vs. unfamiliar child faces? 3) Are parental ERP responses to child faces associated with relevant indicators of parenting quality? As the number of available studies is relatively small at this point, our analysis was not intended to provide confirmatory evidence regarding the key questions but rather to present a preliminary statistical evaluation of the current state of the field, which could help guiding the field forward.

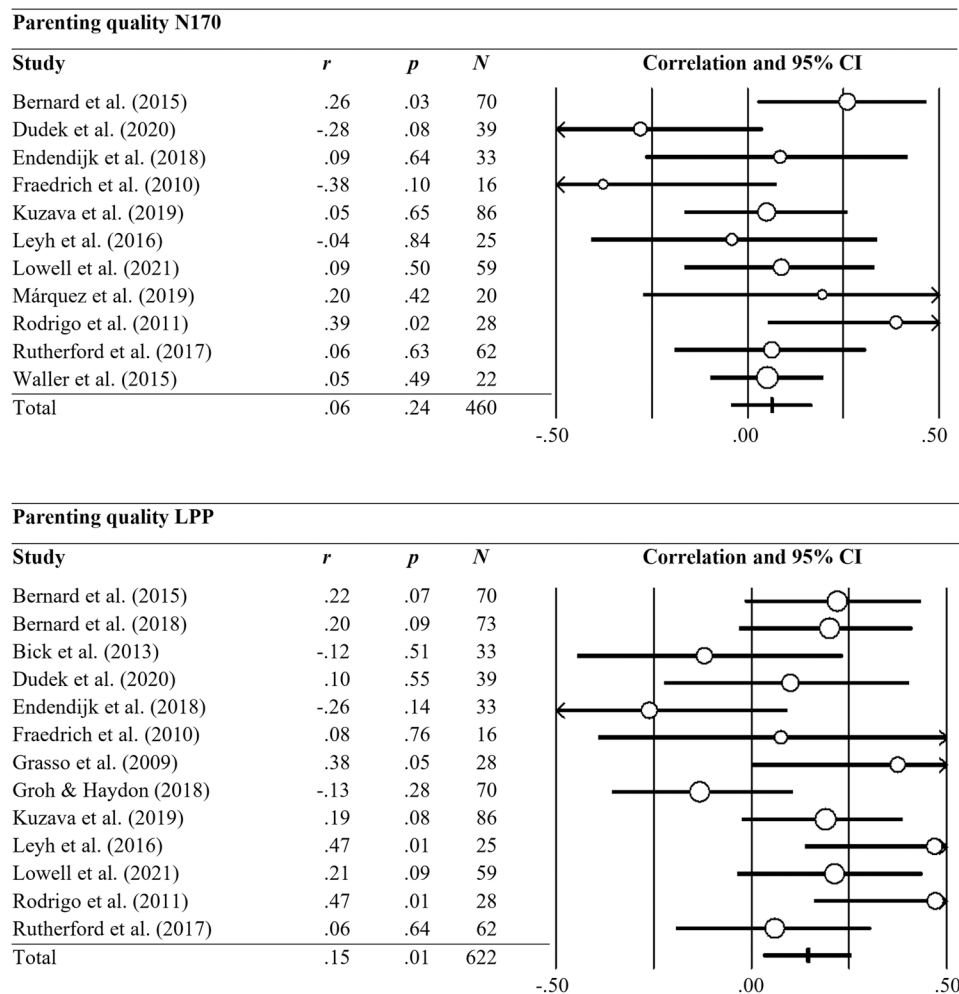
### 4.1. Do parents and non-parents differ in erp responses to child faces?

Any conclusions regarding these analyses should remain cautious due to the very small number of studies comparing parents' and non-parents' ERP responses to child faces. The available studies produced a significant combined effect size for the N170, suggesting that N170 amplitudes to child faces are larger in parents than non-parents. No differences between parents and non-parents were found for the LPP amplitudes, indicating that brain responses reflecting motivated attention and elaborative processing of child faces were not amplified by parenthood. Child faces have been previously found to activate multiple



**Table 5**

Effect sizes and forest plots for studies investigating associations between N170 (above) and LPP (below) responses to child faces and indicators of parenting quality.



Bernard et al. (2015); Bernard et al. (2018); Dudek et al. (2020); Endendijk et al. (2018); Fraedrich et al. (2010); Kuzava et al. (2019); Leyh et al. (2016); Lowell et al. (2021); Márquez et al. (2019); Rodrigo et al. (2011); Rutherford et al. (2017); Waller et al. (2015); Bick et al. (2013); Grasso et al. (2009); Groh and Haydon (2018).

brain regions reflecting perception, attention and emotional processing in both parents and non-parents (Luo et al., 2015). In studies presenting children's faces, activation of the fusiform gyrus, which has also been traced as the main generator of the N170, has been suggested to reflect encoding of "baby schema", i.e., the facial features that are characteristic for infant faces (Glocker et al., 2009; Luo et al., 2015). Therefore, the increased responses to infant faces in parents compared to non-parents at the early visual processing stage could potentially reflect increased encoding of infantile facial features in parents.

As can be observed from Table 3, both the significant combined effect on N170 amplitudes as well as the absence of a combined effect on LPP amplitudes appear to be driven by the large positive N170 and negative LPP effects in Weisman et al. (2012). In that study, the N170 effect appeared to be driven particularly by a large difference in N170 modulation by infant faces between mothers and single non-parent women. Although Weisman et al. (2012) found significant differences between parents vs. non-parents also in the P300, in the context of the current meta-analysis the effect (i.e., smaller P300 responses to unfamiliar infant faces in parents vs. non-parents) was opposite to what was found in the two other studies. The suppressed P300 responses in parents compared to non-parents for unfamiliar child pictures was interpreted by the authors to be due to parents allocating attention more strongly to their own child pictures than unfamiliar child pictures.

Although the group comparison was based only on ERP responses to unfamiliar infant faces, during the task parents were presented with own and unfamiliar infant faces.

Clearly, more research is needed with adequately powered sample sizes to more reliably estimate whether parenthood is associated with increased perceptual and attentional brain responses to children's faces. To reliably determine the impact of parental status on ERP responses, matching parents and non-parents in terms of key background variables such as age and education is also important for future studies. In addition, as infant faces appear to trigger larger N170 and LPP responses than adult faces also in non-parent samples (Hahn et al., 2016; Proverbio et al., 2011), it will be important to investigate whether the potential effect of parenthood on ERP responses is specific to infant and child faces, or whether parenthood is also associated with increased ERP responses to adult faces. Regarding the studies included in the current meta-analyses of parity effects, only Peltola et al. (2014) presented the participants with both infant and adult faces. While that study found that parity modulated ERP responses only to infant faces, but not to adult faces, the ERPs to infant and adult faces were analyzed separately and, thus, the critical interaction effect between parity and face age was not tested. Relatedly, there is a lack of ERP studies systematically varying stimulus face age. Such an approach would be important for determining the age at which the enhanced attentional (e.g.,

Thompson-Booth et al., 2014) or neural responses to infantile features begin to wane.

#### 4.2. Are parents' ERP responses larger to own child faces than to unfamiliar child faces?

In these analyses, the N170 amplitudes did not differentiate own from unfamiliar child faces, but parents' LPP responses were consistently larger to own child faces. The absence of a familiarity effect on the N170 is in line with research investigating the temporal aspects of face familiarity processing in the brain. While the N170 represents the structural encoding of the face configuration and is typically unaffected by face familiarity (Bentin and Deouell, 2000; Eimer, 2000), familiarity begins to modulate ERP amplitudes slightly later at the level of the N250 component (e.g., Tanaka et al., 2006).

The studies reporting LPP quite systematically pointed to larger LPP responses to own vs. unfamiliar child faces. The dataset also included studies that had excellent power to detect the combined effect size, although some samples were clearly underpowered even for a within-subjects design. Although there were an insufficient number of studies for performing a moderation analysis of task type, the effect sizes appeared not to be related to the paradigm used to obtain LPP or P3 data, as positive effects were observed both in passive viewing (e.g., Bernard et al., 2018) and oddball tasks (e.g., Weisman et al., 2012). However, it remains to be determined whether LPP responses to own child stimuli are modulated by attentional focus, i.e., whether attention is explicitly focused on specific features of the stimuli instead of passive viewing (cf. Hajcak et al., 2006). Since only one of the studies included a task requiring emotional target detection (Doi and Shinohara, 2012a), it cannot be determined whether task requirements have an effect on LPP to own child faces. Furthermore, most studies presented neutral stimuli and, therefore, the potential moderation effect of stimulus emotion could not be investigated. Larger LPP amplitudes are typically observed in response to stimuli with motivational significance, such as emotional stimuli of both positive and negative valence as compared to neutral stimuli, and to stimuli associated with high arousal (Olofsson et al., 2008; Schupp et al., 2000, 2007). Importantly, the larger LPP to pictures of own children does not appear to merely reflect the greater familiarity of own child stimuli. In studies that have presented parents with both unfamiliar and familiarized child faces, LPP responses have typically been larger to own child compared to both familiarized and unfamiliar child faces (Bernard et al., 2018; Bick et al., 2013; Grasso et al., 2009; Kuzava and Bernard, 2018). Larger parental LPP responses to own child pictures therefore likely indicate the motivational and emotional significance associated with own child cues, which is in line with fMRI studies that have demonstrated increased activation in key brain regions reflecting emotion and reward processing in parents in response to own child faces (for a review, see Luo et al., 2015). This makes the LPP a particularly relevant candidate for investigating the associations between neural processing of child faces and indicators of parenting quality.

#### 4.3. Are parents' ERP responses associated with indicators of parenting quality?

The N170 effect sizes were generally small and the combined effect size was not significant, although a few individual studies observed larger positive effects between N170 amplitudes and parenting outcomes including observed sensitivity (Bernard et al., 2015; Márquez et al., 2019) and parental neglect (Rodrigo et al., 2011). In the current analysis, the type of parenting quality indicator did not significantly moderate the N170 effect sizes although the effects appeared to be more positive in studies using observation-based measures. As there were not enough studies to test moderation effects of emotional vs. neutral stimuli, or own vs. unfamiliar child faces, it remains for future studies to investigate whether the potential associations between the N170 and parenting outcomes are influenced by these factors.

For LPP responses, the combined effect size was significant, showing

that larger LPP amplitudes to child faces were associated with more favorable indicators of parenting quality. The association between LPP amplitudes and parenting quality was not moderated by any of the relevant moderators (face familiarity, face emotion, reference scheme or type of parenting quality indicator). However, the small number of studies and the use of various experimental designs and outcome indicators may have concealed potential moderating effects.

In the other meta-analyses, LPP responses were consistently larger to own vs. unfamiliar child faces in parents, but the impact of parenthood on LPPs to unfamiliar child faces (i.e., compared to non-parents) was unclear due to small number of studies. Parenthood has been found to potentiate attentional engagement to infant faces, suggesting that infant faces are generally more salient and arousing stimuli for parents than for non-parents (Thompson-Booth et al., 2014). It could thus be expected that the increased attention of parents to infant faces would be also reflected in attention-related ERP responses to unfamiliar infant faces. Consequently, it is an open question whether parental LPP responses to both own and unfamiliar child faces may be associated with indicators of parenting quality. Although in the current meta-analysis face familiarity did not have a moderating effect on the associations between LPP amplitudes and indicators of parenting quality, in the future it will be important to systematically evaluate whether LPP responses to own child and unfamiliar child faces are equally associated with parenting outcomes. While own child faces clearly represent greater motivational significance and ecological validity, a major benefit of unfamiliar faces is that they can be standardized more thoroughly and the same exact stimuli can be presented to each participant, thus increasing the reliability of the ERP-parenting associations.

Although the moderation effect of stimulus type (i.e., whether the effects were based on emotional vs. neutral faces) on the associations between LPP and parenting quality was non-significant, the effect sizes appeared slightly larger for studies presenting emotional faces than for studies including only neutral faces. It could be speculated that the larger effect is driven by increased attention to emotional faces in more sensitive parents, since responsivity to changes in the infant's emotions is a central aspect of sensitive parenting (Ainsworth et al., 1978). Future studies should investigate whether associations between the LPP and parenting outcomes are dependent on attentional focus on emotions by more systematically comparing effect sizes between tasks in which attention is directed to the emotional content of the stimuli and tasks involving passive viewing or emotionally neutral tasks.

A potential reason for the absence of clear moderation effects is the inclusion of diverse parenting quality indicators. The parenting quality indicators included measures of parental neglect based on CPS records, observed parental sensitivity, adult attachment assessments, self-reports and interviews of the parent-child relationship. Due to a small number of studies including self-reports and interviews, the moderation analysis only contrasted studies with attachment-based or observational measures (with the study based on CPS records included as an observational measure). Although the type of parenting outcome measure was not found to moderate the association between LPP amplitudes and parenting quality outcomes, the small number of studies makes it difficult to reliably compare the moderation effects. Accumulation of studies and, ideally, systematic investigations of the different outcome measures and their association with LPP responses will lead to more reliable conclusions regarding the important preliminary finding linking LPP responses with parenting outcomes. It could be investigated, for example, whether parental neglect and intrusive behavior during interaction are differently associated with LPP amplitudes, since they represent somewhat opposing parenting behaviors. Given that LPP amplitudes reflect attentional engagement, increased LPP responses to child faces could be a marker of non-neglectful/sensitive caregiving (Fraedrich et al., 2010; Kuzava et al., 2019; Rodrigo et al., 2011) but equally a marker of disproportional attention to infant cues or intrusiveness (cf. Groh & Haydon, 2019). It will be important to determine the experimental conditions and type of stimuli that could distinguish

between LPP responses associated with sensitive vs. intrusive parenting. Further research is also necessary to determine the true effect size between LPP and parenting outcomes, as the power analysis indicated that all of the studies included in the meta-analysis were underpowered to detect the association of  $r = 0.15$  in a correlational design.

## 5. Conclusions

A systematic analysis of the emerging parental ERP literature supports the view (e.g., Maupin et al. (2015) that ERP responses to child-related stimuli provide useful information for assessing the parental brain. The findings of this meta-analysis suggest that ERPs in the later processing stage (LPP or P3 responses) could be relevant indicators for assessing attentional-motivational factors related to parenting, since these responses were found to be consistently larger for own child faces and they were also associated with parenting outcomes including observed sensitivity and parents' secure attachment representations. Although the earlier N170 response differed between parents and non-parents, it was not affected by face familiarity or variation in parenting quality outcomes. Since the N170 is related to structural encoding of face features (Bentin and Deouell, 2000; Eimer, 2000), it could be less susceptible to motivational factors or experience in parenting. In accordance, a recent behavioral study found that perinatal status (pre- vs. postnatal) was unrelated to perceptual processing of infant emotional expressions (Parsons et al., 2021). However, the conclusions related to the N170 should be cautious because of the small number of studies.

The results provide preliminary support for the potential of the LPP (or P3) as a neural correlate of parenting quality when measured in response to children's face stimuli. More research is needed to clarify whether the association between LPP and parenting quality is evident for both own and unfamiliar faces and regardless of facial expressions of the stimulus faces, and whether different EEG paradigms impact the strength of the associations, specifically regarding whether or not the task requires focusing attention on the emotional content of the stimuli. It will also be important to determine which types of parenting quality indicators are most reliably associated with LPP responses, and whether the LPP, as an indicator of motivated attention, similarly reflects both sensitive and intrusive parenting behaviors. Relatedly, the influence of parental depressive and anxiety symptoms on neural responses toward child stimuli is a topic requiring greater attention (e.g., Arteche et al., 2011).

As the studies included in the current dataset were largely underpowered to detect the rather small association between LPP and parenting outcomes, it remains to be determined whether  $r = 0.15$  reflects the true size of the association. Researchers might be advised to strive for larger sample sizes in future studies investigating how ERP response are associated with parenting quality, for example through multi-site collaboration. Furthermore, as this is a relatively young field of research, much of the data analyses may have been conducted in an exploratory fashion. In the future, to fulfill the promise of this line of research, it will be important to adhere to established guidelines for ERP/EEG research (Keil et al., 2014; Luck and Gaspelin, 2017) and, ideally, strive towards more confirmatory analyses by pre-registering study protocols and analysis plans (Paul et al., 2021). In the same vein, we note that the current meta-analysis has not been pre-registered either. Methodological variation in EEG recording parameters such as the choice of reference electrodes may also influence the outcomes (see Kuzava et al., 2020), and such choices should depend on the aims of the study (e.g., whether the primary aim is to analyze N170 or LPP responses).

Finally, another important and an emerging (Bakermans-Kranenburg et al., 2019) research target is to extend the investigation of ERP responses to child-related cues systematically to fathers. As only a few studies of the current meta-analysis included fathers as participants (Proverbio et al., 2006; Waller et al., 2015; Weisman et al., 2012),

comparisons between female and male parents were not possible. There is some preliminary evidence for both similarity of parental brain activation to infant stimuli in males and females (Abraham et al., 2014) as well as differences in behavioral responses to infant cues in mothers and fathers (Parsons et al., 2017). Therefore, investigation of gender differences, different caregiving roles and arrangements (e.g., homosexual couples; Abraham et al., 2014), and the influence of the amount of involvement in child care on parental brain responses towards child cues are relevant targets for future research.

## Declarations of interest

none.

## Acknowledgements

This research was supported by grants from the Academy of Finland (#307657 and # 321424).

## References

- Abraham, E., Hendl, T., Shapira-Lichter, I., Kanat-Maymon, Y., Zagoory-Sharon, O., Feldman, R., 2014. Father's brain is sensitive to childcare experiences. *Proc. Natl. Acad. Sci.* 111 (27), 201402569. <https://doi.org/10.1073/pnas.1402569111>.
- Ainsworth, M.D.S., Blehar, M.C., Waters, E., Wall, S., 1978. *Patterns of Attachment: A Psychological Study of the Strange Situation*. Erlbaum.
- Arteche, A., Joormann, J., Harvey, A., Craske, M., Gotlib, I.H., Lehtonen, A., Counsell, N., Stein, A., 2011. The effects of postnatal maternal depression and anxiety on the processing of infant faces. *J. Affect. Disord.* 133 (1), 197–203. <https://doi.org/10.1016/j.jad.2011.04.015>.
- Bakermans-Kranenburg, M.J., Lotz, A., Alyousefi-van Dijk, K., van IJzendoorn, M.H., 2019. Birth of a father: fathering in the first 1,000 days. *Child Dev. Perspect.* 13 (4), 247–253. <https://doi.org/10.1111/cdep.12347>.
- Bakermans-Kranenburg, M.J., van IJzendoorn, M.H., Juffer, F., 2003. Less is more: meta-analyses of sensitivity and attachment interventions in early childhood. *Psychol. Bull.* 129 (2), 195–215. <https://doi.org/10.1037/0033-2909.129.2.195>.
- Bakermans-Kranenburg, M.J., Verhees, M.W. F.T., Lotz, A.M., Alyousefi-van Dijk, K., van IJzendoorn, M.H., 2021. Is paternal oxytocin an oxymoron? Oxytocin, vasopressin, testosterone, estradiol, and cortisol in emerging fatherhood. *Philosophical Transactions of the Royal Society B, Biological Sciences*.
- Bartels, A., Zeki, S., 2004. The neural correlates of maternal and romantic love. *NeuroImage* 21 (3), 1155–1166. <https://doi.org/10.1016/j.neuroimage.2003.11.003>.
- Batty, M., Taylor, M.J., 2003. Early processing of the six basic facial emotional expressions. *Cogn. Brain Res.* 17 (3), 613–620. [https://doi.org/10.1016/S0926-6410\(03\)00174-5](https://doi.org/10.1016/S0926-6410(03)00174-5).
- Bentin, S., Allison, T., Puce, A., Perez, E., McCarthy, G., 1996. Electrophysiological studies of face perception in humans. *J. Cogn. Neurosci.* 8 (6), 551–565. <https://doi.org/10.1162/jocn.1996.8.6.551>.
- Bentin, S., Deouell, L.Y., 2000. Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cogn. Neuropsychol.* 17 (1–3), 35–55. <https://doi.org/10.1080/026432900380472>.
- Bernard, K., Kuzava, S., Simons, R., Dozier, M., 2018. CPS-referred mothers' psychophysiological responses to own versus other child predict sensitivity to child distress. *Dev. Psychol.* 54 (7), 1255–1264. <https://doi.org/10.1037/dev0000508>.
- Bernard, K., Simons, R., Dozier, M., 2015. Effects of an attachment-based intervention on child protective services-referred mothers' event-related potentials to children's emotions. *Child Dev.* 86 (6), 1673–1684. <https://doi.org/10.1111/cdev.12418>.
- Bick, J., Dozier, M., Bernard, K., Grasso, D., Simons, R., 2013. Foster mother-infant bonding: associations between foster mothers' oxytocin production, electrophysiological brain activity, feelings of commitment, and caregiving quality. *Child Dev.* 84 (3), 826–840. <https://doi.org/10.1111/cdev.12008>.
- Borenstein, M., Rothstein, D., Cohen, J., 2013. *Comprehensive meta-analysis: a computer program for research synthesis*. Biostat, Englewood, NJ.
- Bornstein, M.H., Arterberry, M.E., Mash, C., 2013. Differentiated brain activity in response to faces of own versus unfamiliar babies in primipara mothers: an electrophysiological study. *Dev. Neuropsychol.* 38 (6), 365–385. <https://doi.org/10.1080/87565641.2013.804923>.
- Bradley, M.M., 2009. Natural selective attention: orienting and emotion. *Psychophysiology* 46 (1), 1–11. <https://doi.org/10.1111/j.1469-8986.2008.00702.x>.
- Carmel, D., Bentin, S., 2002. Domain specificity versus expertise: factors influencing distinct processing of faces. *Cognition* 83 (1), 1–29. [https://doi.org/10.1016/S0010-0277\(01\)00162-7](https://doi.org/10.1016/S0010-0277(01)00162-7).
- Cuthbert, B.N., Schupp, H.T., Bradley, M.M., Birbaumer, N., Lang, P.J., 2000. Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biol. Psychol.* 52 (2), 95–111. [https://doi.org/10.1016/S0301-0511\(99\)00044-7](https://doi.org/10.1016/S0301-0511(99)00044-7).



- Deans, C.L., 2020. Maternal sensitivity, its relationship with child outcomes, and interventions that address it: a systematic literature review. *Early Child Dev. Care* 190 (2), 252–275. <https://doi.org/10.1080/03004430.2018.1465415>.
- DeBruine, L.M., Hahn, A.C., Jones, B.C., 2016. Perceiving infant faces. *Curr. Opin. Psychol.* 7, 87–91. <https://doi.org/10.1016/j.copsyc.2015.08.010>.
- Doi, H., Shinohara, K., 2012a. Event-related potentials elicited in mothers by their own and unfamiliar infants' faces with crying and smiling expression. *Neuropsychologia* 50 (7), 1297–1307. <https://doi.org/10.1016/j.neuropsychologia.2012.02.013>.
- Doi, H., Shinohara, K., 2012b. Electrophysiological responses in mothers to their own and unfamiliar child's gaze information. *Brain Cogn.* 80 (2), 266–276. <https://doi.org/10.1016/j.bandc.2012.07.009>.
- Dudek, J., Colasante, T., Zuffiano, A., Haley, D.W., 2020. Changes in cortical sensitivity to infant facial cues from pregnancy to motherhood predict mother–infant bonding. *Child Dev.* 91 (1), e198–e217. <https://doi.org/10.1111/cdev.13182>.
- Eimer, M., 2000. Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clin. Neurophysiol.* 111 (4), 694–705. [https://doi.org/10.1016/S1388-2457\(99\)00285-0](https://doi.org/10.1016/S1388-2457(99)00285-0).
- Eimer, M., 2011. The face-sensitive N170 component of the event-related brain potential. In: Rhodes, G., Calder, A., Johnson, M., Haxby, J.V. (Eds.), *Oxford Handbook of Face Perception*. Oxford University Press, pp. 329–344. <https://doi.org/10.1093/oxfordhb/9780199559053.013.0017>.
- Eimer, M., Holmes, A., 2002. An ERP study on the time course of emotional face processing. *Neuroreport* 13 (4), 427–431. <https://doi.org/10.1097/00001756-200203250-00013>.
- Endendijk, J.J., Spencer, H., van Baar, A.L., Bos, P.A., 2018. Mothers' neural responses to infant faces are associated with activation of the maternal care system and observed intrusiveness with their own child. *Cogn., Affect. Behav. Neurosci.* 1–13. <https://doi.org/10.3758/s13415-018-0592-6>.
- Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* 39 (2), 175–191. <https://doi.org/10.3758/BF03193146>.
- Ferrari, V., Codispoti, M., Cardinale, R., Bradley, M.M., 2008. Directed and motivated attention during processing of natural scenes. *J. Cogn. Neurosci.* 20 (10), 1753–1761. <https://doi.org/10.1162/jocn.2008.20121>.
- Foti, D., Hajcak, G., 2008. Deconstructing reappraisal: descriptions preceding arousing pictures modulate the subsequent neural response. *J. Cogn. Neurosci.* 20 (6), 977–988. <https://doi.org/10.1162/jocn.2008.20066>.
- Fraedrich, E.M., Lakatos, K., Spangler, G., 2010. Brain activity during emotion perception: the role of attachment representation. *Attach. Hum. Dev.* 12 (3), 231–248. <https://doi.org/10.1080/14616731003759724>.
- Gao, C., Conte, S., Richards, J.E., Xie, W., Hanayik, T., 2019. The neural sources of N170: understanding timing of activation in face-selective areas. *Psychophysiology* 56 (6), e13336. <https://doi.org/10.1111/psyp.13336>.
- Glockner, M.L., Langleben, D.D., Ruparel, K., Loughead, J.W., Valdez, J.N., Griffin, M.D., Sachser, N., Gur, R.C., 2009. Baby schema modulates the brain reward system in nulliparous women. *Proc. Natl. Acad. Sci.* 106 (22), 9115–9119. <https://doi.org/10.1073/pnas.0811620106>.
- Grasso, D.J., Moser, J.S., Dozier, M., Simons, R., 2009. ERP correlates of attention allocation in mothers processing faces of their children. *Biol. Psychol.* 81 (2), 95–102. <https://doi.org/10.1016/j.biopsycho.2009.03.001>.
- Groh, A.M., Haydon, K.C., 2018. Mothers' neural and behavioral responses to their infants' distress cues: the role of secure base script knowledge. *Psychol. Sci.* 29 (2), 242–253. <https://doi.org/10.1177/0956797617730320>.
- Hahn, A.C., Symons, L.A., Kredel, T., Hanson, K., Schiavone, L., Jantzen, K.J., 2016. Early and late event-related potentials are modulated by infant and adult faces of high and low attractiveness. *Soc. Neurosci.* 11 (2), 207–220. <https://doi.org/10.1080/17470919.2015.1059361>.
- Hajcak, G., Dunning, J.P., Foti, D., 2009. Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clin. Neurophysiol.* 120 (3), 505–510. <https://doi.org/10.1016/j.clinph.2008.11.028>.
- Hajcak, G., Foti, D., 2020. Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: an integrative review. *Psychophysiology* 57 (7), 1–15. <https://doi.org/10.1111/psyp.13570>.
- Hajcak, G., Moser, J.S., Simons, R.F., 2006. Attending to affect: appraisal strategies modulate the electrocortical response to arousing pictures. *Emotion* 6 (3), 517–522. <https://doi.org/10.1037/1528-3542.6.3.517>.
- Hajcak, G., Nieuwenhuis, S., 2006. Reappraisal modulates the electrocortical response to unpleasant pictures. *Cogn., Affect., Behav. Neurosci.* 6 (4), 291–297. <https://doi.org/10.3758/CABN.6.4.291>.
- Hinojosa, J.A., Mercado, F., Carretié, L., 2015. N170 sensitivity to facial expression: a meta-analysis. *Neurosci. Biobehav. Rev.* 55, 498–509. <https://doi.org/10.1016/j.neubiorev.2015.06.002>.
- Hoekzema, E., Barba-Müller, E., Pozzobon, C., Picado, M., Lucco, F., García-García, D., Soliva, J.C., Tobeña, A., Desco, M., Crone, E.A., Ballesteros, A., Carmona, S., Vilarroya, O., 2017. Pregnancy leads to long-lasting changes in human brain structure. *Nat. Neurosci.* 20, 287–296. <https://doi.org/10.1038/nn.4458>.
- Holmes, A., Vuilleumier, P., Eimer, M., 2003. The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. *Cogn. Brain Res.* 16 (2), 174–184. [https://doi.org/10.1016/S0926-6410\(02\)00268-9](https://doi.org/10.1016/S0926-6410(02)00268-9).
- Huffmeijer, R., Bakermans-Kranenburg, M.J., Alink, L.R.A., van IJzendoorn, M.H., 2014. Reliability of event-related potentials: the influence of number of trials and electrodes. *Physiol. Behav.* 130, 13–22. <https://doi.org/10.1016/j.physbeh.2014.03.008>.
- Keil, A., Debener, S., Gratton, G., Junghöfer, M., Kappenman, E.S., Luck, S.J., Luu, P., Miller, G. a, Yee, C.M., 2014. Committee report: publication guidelines and recommendations for studies using electroencephalography and magnetoencephalography. *Psychophysiology* 51 (1), 1–21. <https://doi.org/10.1111/psyp.12147>.
- Kim, P., 2016. Human maternal brain plasticity: adaptation to parenting. *N. Dir. Child Adolesc. Dev.* 153, 47–58. <https://doi.org/10.1002/cad>.
- Kim, P., Leckman, J.F., Mayes, L.C., Feldman, R., Wang, X., Swain, J.E., 2010. The plasticity of human maternal brain: Longitudinal changes in brain anatomy during the early postpartum period. *Behavioral Neuroscience* 124 (5), 695–700. <https://doi.org/10.1037/a0020884>.
- Kringelbach, M.L., Stark, E.A., Alexander, C., Bornstein, M.H., Stein, A., 2016. On cuteness: unlocking the parental brain and beyond. *Trends Cogn. Sci.* 20 (7), 545–558. <https://doi.org/10.1016/j.tics.2016.05.003>.
- Kuzava, S., Bernard, K., 2018. Maternal report of infant negative affect predicts attenuated brain response to own infant. *Dev. Psychobiol.* 60 (8), 927–937. <https://doi.org/10.1002/dev.21749>.
- Kuzava, S., Frost, A., Perrone, L., Kang, E., Lindhiem, O., Bernard, K., 2020. Adult processing of child emotional expressions: a meta-analysis of ERP studies. *Dev. Psychol.* 56 (6), 1170–1190. <https://doi.org/10.1037/dev0000928>.
- Kuzava, S., Nissim, G., Frost, A., Nelson, B., Bernard, K., 2019. Latent profiles of maternal neural response to infant emotional stimuli: associations with maternal sensitivity. *Biol. Psychol.* 143, 113–120. <https://doi.org/10.1016/j.biopsycho.2019.02.009>.
- Leibenluft, E., Gobbini, M.I., Harrison, T., Haxby, J.V., 2004. Mothers' neural activation in response to pictures of their children and other children. *Biol. Psychiatry* 56 (4), 225–232. <https://doi.org/10.1016/j.biopsycho.2004.05.017>.
- Leppänen, J.M., Moulson, M.C., Vogel-Farley, V.K., Nelson, C.A., 2007. An ERP study of emotional face processing in the adult and infant brain. *Child Dev.* 78 (1), 232–245. <https://doi.org/10.1111/j.1467-8624.2007.00994.x>.
- Leyh, R., Heinisch, C., Behringer, J., Reiner, I., Spangler, G., 2016. Maternal attachment representation and neurophysiological processing during the perception of infants' emotional expressions. *Plos One* 11 (2), e0147294. <https://doi.org/10.1371/journal.pone.0147294>.
- Lowell, A.F., Dell, J., Potenza, M.N., Strathearn, L., Mayes, L.C., Rutherford, H.J.V., 2021. Adult attachment is related to maternal neural response to infant cues: an ERP study. *Attach. Hum. Dev.* <https://doi.org/10.1080/14616734.2021.1880057>.
- Luck, S.J., Gaspelin, N., 2017. How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology* 54 (1), 146–157. <https://doi.org/10.1111/psyp.12639>.
- Luo, L., Ma, X., Zheng, X., Zhao, W., Xu, L., Becker, B., Kendrick, K., 2015. Neural systems and hormones mediating attraction to infant and child faces. *Front. Psychol.* 6, 970. <https://doi.org/10.3389/fpsyg.2015.00970>.
- Malak, S.M., Crowley, M.J., Mayes, L.C., Rutherford, H.J.V., 2014. Maternal anxiety and neural responses to infant faces. *J. Affect. Disord.* 172C, 324–330. <https://doi.org/10.1016/j.jad.2014.10.013>.
- Márquez, C., Nicolini, H., Crowley, M.J., Solís-Vivanco, R., 2019. Early processing (N170) of infant faces in mothers of children with autism spectrum disorder and its association with maternal sensitivity. *Autism Res.* 12 (5), 744–758. <https://doi.org/10.1002/aur.2102>.
- Maupin, A.N., Hayes, N.J., Mayes, L.C., Rutherford, H.J.V., 2015. The application of electroencephalography to investigate the neural bases of parenting: a review. *Parent., Sci. Pract.* 15 (1), 9–23. <https://doi.org/10.1080/15295192.2015.992735>.
- Moran, T.P., Jendrusina, A.A., Moser, J.S., 2013. The psychometric properties of the late positive potential during emotion processing and regulation. *Brain Res.* 1516, 66–75. <https://doi.org/10.1016/j.brainres.2013.04.018>.
- Moser, J.S., Hajcak, G., Bukay, E., Simons, R.F., 2006. Intentional modulation of emotional responding to unpleasant pictures: an ERP study. *Psychophysiology* 43 (3), 292–296. <https://doi.org/10.1111/j.1469-8986.2006.00402.x>.
- Noll, L.K., Mayes, L.C., Rutherford, H.J.V., 2012. Investigating the impact of parental status and depression symptoms on the early perceptual coding of infant faces: an event-related potential study. *Soc. Neurosci.* 7 (5), 525–536. <https://doi.org/10.1080/17470919.2012.672457>.
- Olofsson, J.K., Nordin, S., Sequeira, H., Polich, J., 2008. Affective picture processing: an integrative review of ERP findings. *Biol. Psychol.* 77 (3), 247–265. <https://doi.org/10.1016/j.biopsycho.2007.11.006>.
- Parsons, C.E., Nummenmaa, L., Sinervä, E., Korja, R., Kajaanoja, J., Young, K.S., Karlsson, H., Karlsson, L., 2021. Investigating the effects of perinatal status and gender on adults' responses to infant and adult facial emotion. *Emotion* 21 (2), 337–349. <https://doi.org/10.1037/emo0000698>.
- Parsons, C.E., Stark, E.A., Young, K.S., Stein, A., Kringelbach, M.L., 2013. Understanding the human parental brain: a critical role of the orbitofrontal cortex. *Soc. Neurosci.* Vol. 8 (Issue 6), 525–543. <https://doi.org/10.1080/17470919.2013.842610>.
- Parsons, C.E., Young, K.S., Elmholt, E.-M.J., Stein, A., Kringelbach, M.L., Jegindoe Elmholt, E.-M., Stein, A., Kringelbach, M.L., 2017. Interpreting infant emotional expressions: parenthood has differential effects on men and women. *Q. J. Exp. Psychol.* 70, 554–564. <https://doi.org/10.1080/17470218.2016.1141967>.
- Paul, M., Govaert, G.H., Schettino, A., 2021. Making ERP research more transparent: guidelines for preregistration. *Int. J. Psychophysiol.* 164, 52–63. <https://doi.org/10.1016/j.ijpsycho.2021.02.016>.
- Peltola, M.J., Strathearn, L., Puura, K., 2018. Oxytocin promotes face-sensitive neural responses to infant and adult faces in mothers. *Psychoneuroendocrinology* 91, 261–270. <https://doi.org/10.1016/j.psyneuen.2018.02.012>.
- Peltola, M.J., Yrttiaho, S., Puura, K., Proverbio, A.M., Mononen, N., Lehtimäki, T., Leppänen, J.M., 2014. Motherhood and oxytocin receptor genetic variation are associated with selective changes in electrocortical responses to infant facial expressions. *Emotion* 14 (3), 469–477. <https://doi.org/10.1037/a0035959>.

- Polich, J., 2007. Updating P300: an integrative theory of P3a and P3b. *Clin. Neurophysiol.* 118 (10), 2128–2148. <https://doi.org/10.1016/j.clinph.2007.04.019>.
- Proverbio, A.M., Brignone, V., Matarazzo, S., Del Zotto, M., Zani, A., 2006. Gender and parental status affect the visual cortical response to infant facial expression. *Neuropsychologia* 44 (14), 2987–2999. <https://doi.org/10.1016/j.neuropsychologia.2006.06.015>.
- Proverbio, A.M., Riva, F., Zani, A., Martin, E., 2011. Is it a baby? Perceived age affects brain processing of faces differently in women and men. *J. Cogn. Neurosci.* 23 (11), 3197–3208. [https://doi.org/10.1162/jocn\\_a\\_00041](https://doi.org/10.1162/jocn_a_00041).
- Rilling, J.K., 2013. The neural and hormonal bases of human parental care. *Neuropsychologia* 51 (4), 731–747. <https://doi.org/10.1016/j.neuropsychologia.2012.12.017>.
- Rodrigo, M.J., León, I., Quiñones, I., Lage, A., Byrne, S., Bobes, M.A., Leon, I., Quinones, I., Lage, A., Byrne, S., Bobes, M.A., 2011. Brain and personality bases of insensitivity to infant cues in neglectful mothers: an event-related potential study. *Dev. Psychopathol.* 23 (1), 163–176. <https://doi.org/10.1017/S0954579410000714>.
- Rutherford, H.J.V., Maupin, A.N., Landi, N., Potenza, M.N., Mayes, L.C., 2017. Parental reflective functioning and the neural correlates of processing infant affective cues. *Soc. Neurosci.* 12 (5), 519–529. <https://doi.org/10.1080/17470919.2016.1193559>.
- Schupp, H.T., Cuthbert, B.N., Bradley, M.M., Cacioppo, J.T., Ito, T., Lang, P.J., 2000. Affective picture processing: the late positive potential is modulated by motivational relevance. *Psychophysiology* 37 (2), 257–261. <https://doi.org/10.1111/1469-8986.3720257>.
- Schupp, H.T., Junghöfer, M., Weike, A.I., Hamm, A.O., 2003. Emotional facilitation of sensory processing in the visual cortex. *Psychol. Sci.* 14 (1), 7–13. <https://doi.org/10.1111/1467-9280.01411>.
- Schupp, H.T., Stockburger, J., Codispoti, M., Junghofer, M., Weike, A.I., Hamm, A.O., 2007. Selective visual attention to emotion. *J. Neurosci.* 27 (5), 1082–1089. <https://doi.org/10.1523/JNEUROSCI.3223-06.2007>.
- Simonsohn, U., Nelson, L.D., Simmons, J.P., 2014. p-Curve and effect size: correcting for publication bias using only significant results. *Perspect. Psychol. Sci.* 9 (6), 666–681. <https://doi.org/10.1177/1745691614553988>.
- Tabachnick, B.G., Fidell, L.S., 2001. *Using Multivariate Statistics*, 4. Allyn & Bacon.
- Tanaka, J.W., Curran, T., Porterfield, A.L., Collins, D., 2006. Activation of preexisting and acquired face representations: the N250 event-related potential as an index of face familiarity. *J. Cogn. Neurosci.* 18 (9), 1488–1497. <https://doi.org/10.1162/jocn.2006.18.9.1488>.
- Thompson-Booth, C., Viding, E., Mayes, L.C., Rutherford, H.J.V., Hodsoll, S., McCrory, E. J., 2014. Here's looking at you, kid: attention to infant emotional faces in mothers and non-mothers. *Dev. Sci.* 17 (1), 35–46. <https://doi.org/10.1111/desc.12090>.
- Verhage, M.L., Fearon, R.M.P., Schuengel, C., van IJzendoorn, M.H., Bakermans-Kranenburg, M.J., Madigan, S., Roisman, G.I., Oosterman, M., Behrens, K.Y., Wong, M.S., Mangelsdorf, S., Priddis, L.E., Brisch, K.-H., 2018. Examining ecological constraints on the intergenerational transmission of attachment Via individual participant data meta-analysis. *Child Dev.* 89 (6), 2023–2037. <https://doi.org/10.1111/cdev.13085>.
- Verhage, M.L., Schuengel, C., Madigan, S., Fearon, R.M.P., Oosterman, M., Cassibba, R., Bakermans-Kranenburg, M.J., van IJzendoorn, M.H., 2016. Narrowing the transmission gap: a synthesis of three decades of research on intergenerational transmission of attachment. *Psychol. Bull.* 142 (4), 337–366. <https://doi.org/10.1037/bul0000038>.
- Waller, C., Wittfoth, M., Fritzsche, K., Timm, L., Wittfoth-Schardt, D., Rottler, E., Heinrichs, M., Buchheim, A., Kiefer, M., Gundel, H., 2015. Attachment representation modulates oxytocin effects on the processing of own-child faces in fathers. *Psychoneuroendocrinology* 62, 27–35. <https://doi.org/10.1016/j.psyneuen.2015.07.003>.
- Weisman, O., Feldman, R., Goldstein, A., 2012. Parental and romantic attachment shape brain processing of infant cues. *Biol. Psychol.* 89 (3), 533–538. <https://doi.org/10.1016/j.biopsycho.2011.11.008>.
- Witteman, J., van IJzendoorn, M.H., Rilling, J.K., Bos, P.A., Schiller, N.O., Bakermans-Kranenburg, M.J., 2019. Towards a neural model of infant cry perception. *Neurosci. Biobehav. Rev.* 99, 23–32. <https://doi.org/10.1016/j.neubiorev.2019.01.026>.