The Late Positive Potential in Response to Emotional Stimuli in Parous and Nulliparous Women

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Overview

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Author's Statement: The thesis is a part of the research project BRAINMINT: *Brains and Minds in transition* (PI Lars T. Westlye), carried out at the Department of Psychology, University of Oslo, Norwegian Centre for Mental Disorders Research (NORMENT), and the Oslo University Hospital (OUS). The planning of the thesis was a collaborative effort by my supervisor and me. I developed the hypothesis, conducted statistical analysis of data from EEG, questionnaires, and the response task, quality control and wrote the thesis in whole. I also took part in EEG data collection for the BRAINMINT research project. The response-task paradigm and the preprocessing script was developed by the BRAINMINT research group. Preprocessing for the EEG data was a collaborative effort by Torgeir Moberget and me.

Abstract

Pregnancy and motherhood have been shown to promote neuroplasticity, especially in brain areas critical for emotion processing. However, findings on the effect of parity on electroencephalographic indices of emotion processing are inconsistent. To address this, the present master thesis explored the late positive potential (LPP), an event related potential (ERP) occurring at 300-1000 ms post stimulus presentation that has been robustly found to vary with stimulus valence, in a sample of parous (n = 78) and nulliparous (n = 143) women. The present study is a part of the research project BRAINMINT: *Brains and Minds in transition,* carried out at the Department of Psychology, University of Oslo, Norwegian Centre for Mental Disorders Research (NORMENT), and the Oslo University Hospital (OUS). LPPs were recorded in response to a computerized task, involving presentation of positively, negatively, and neutrally valenced images. The LPP was defined as the mean amplitude over centroparietal electrodes from 300-1000 ms. Analysis of variance (ANOVA) showed highly significant effects of stimulus valence (three levels: positive, negative, and neutral), as well as a significant interaction with parity (two levels: parous, nulliparous), indicating that the effect of stimulus valence differed in parous versus nulliparous women. This significant interaction effect was followed up by computing positive and negative emotional reactivity scores by subtracting the LPP in response to emotional images from LPP in response to neutral images. A reactivity (two levels: positive, negative) by parity (two levels: parous, nulliparous) ANOVA showed differences between parous and nulliparous women on both emotional difference scores, with higher scores in the parous group. Results of both ANOVAs were supported with follow-up ANCOVAs adjusting for sleep quality and age, which differed between groups. Multivariate regression analyses did not show any significant relationships between depression and anxiety symptoms, sleep quality, years since last childbirth and age at first childbirth. In sum, these results provide support for a small yet significant difference in emotion processing in parous and nulliparous women. The findings suggest increased reactivity to positively and negatively valenced images in parous women compared to nulliparous women.

Keywords: Late Positive Potential (LPP), Electroencephalography (EEG), emotion processing, emotion valence, parous, nulliparous.

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Throughout the lifespan, the brain continuously adapts to ever-changing events, both physiological and environmental. This ability of the brain to adapt is referred to as neuroplasticity (Voss et al., 2017). During pregnancy women´s bodies and brains undergo changes to prepare for pregnancy and motherhood and to ensure the fetus's health and development (İnce & Albar, 2022, p.29). After giving birth and postpartum, most pregnancy-related adaptations will return to their preconception state, while others persist following parturition (İnce & Albar, 2022, p.29). In addition to biological changes during pregnancy and postpartum, motherhood brings on a broad repertoire of new challenges and behaviors (Rutherford et al., 2015). The new challenges include caring for infants' physical and emotional needs, such as mentalizing with one's infants' feelings while simultaneously regulating one's own emotions. Emotion regulation refers to the ability to intentionally and/or unintentionally modulate and manage one´s own emotions, and the intensity and duration of said emotions for a more appropriate and adaptive outcome (APA Dictionary of Psychology, n.d.). The trajectory of emotion regulation in motherhood has been shown to decrease slightly during pregnancy and postpartum, followed by a steady increase over the first four years after childbirth (Grolleman et al., 2023). These findings indicate a potential difference in emotion processing in women with a history of childbirth (i.e., parous), and women with no history of childbirth (i.e., nulliparous women). Hence, pregnancy and motherhood are believed to result in pregnancy-induced and experience-depended changes in the brain (Rutherford et al., 2015). To date, little focus has been placed on the effects of parity in neuroscience, yet research on this topic sheds light on the effects of pregnancy and motherhood on neural processing. One way to address this relationship is by comparing brain activity data time-locked to the perception of emotional stimuli in parous and nulliparous women. In this master thesis, this gap in the literature will be addressed. First, previous findings on neuroplasticity that takes place in pregnancy and motherhood, with focus on regions and networks implicated in emotion processing, will be reviewed. Second, research on electroencephalography (EEG), specifically event-related potentials (ERPs) comparing differences in emotion processing in parous and nulliparous women will be further discussed. Specifically, how the late positive potential can be utilized to further explore the relationship between parity and emotion processing. Factors that may affect this relationship will also be addressed. Lastly, building

on the review of the literature, the late positive potential in response to emotionally valenced stimuli will be compared in a sample of parous (n = 78) and nulliparous (n = 143) women.

Neuroplasticity in pregnancy and motherhood

The neuroendocrine system plays a critical role in the physiological changes observed during pregnancy and postpartum (Russell et al., 2001). These changes include hormonal fluctuations in oxytocin, estrogens, and progesterone, among others (Levine et al., 2007; Rehbein et al., 2021). Although, hormonal levels largely recover to preconception states, shorter menstrual cycles and lower levels of estradiol, the most potent and prevalent estrogen in the female body, have been reported in parous compared to nulliparous women (Barrett et al., 2014; Dorgan et al., 1995). Estrogen and progesterone receptors are expressed in brain regions critical for emotion processing, e.g., the amygdala, hippocampus, anterior cingulate, and orbitofrontal cortex, and have been linked to neuroplastic processes (Amin et al., 2006; Barth et al., 2015; Goldstein et al., 2005; Protopopescu et al., 2005; Rehbein et al., 2021). Therefore, in view of the hormonal fluctuations during pregnancy and postpartum, these periods are recognized as periods of increased neuroplasticity, potentially resulting in differences in emotion processing in parous and nulliparous women (Rehbein et al., 2021).

The notion of increased neuroplasticity during pregnancy and postpartum has received considerable support from the neuroimaging literature using both structural and functional imaging techniques (Hoekzema et al., 2017, 2022; Kim et al., 2010; Moses-Kolko et al., 2021; Oatridge et al., 2002). Longitudinal studies utilizing structural magnetic resonance imaging (MRI) comparing women preconception to pregnancy and early postpartum demonstrated gray matter volume (GMV) reductions in overall brain volume and in areas critical for emotion processing (Hoekzema et al., 2017; Hoekzema et al., 2022; Oatridge et al., 2002). Further supporting pregnancy-specific brain alterations, these longitudinal changes were not present in nulliparous women and fathers when measured at the same timepoints. (Hoekzema et al., 2017; Hoekzema et al., 2022). In Hoekzema et al. (2017) reductions in GMV linked with pregnancy were associated with mother-infant bonding, indicative of its adaptive function. Moreover, these GMV reductions have been shown to be comparable to reductions that occur in adolescence and could therefore include processes such as synaptic pruning, leading to finetuning of emotion processing networks critical for motherhood (Carmona et al., 2019). Consistent with structural findings, functional MRI (fMRI) findings have demonstrated neural activation in several brain regions specific to mothers in response to emotional and social stimuli (Plank et al., 2021). For example, compared to nulliparous

women, parous women showed increased activity in the insula, superior temporal gyrus, and inferior and medial superior frontal gyrus in empathy tasks of viewing scenarios of pain inflicted on others (Plank et al., 2021). Longitudinal findings have also demonstrated increased prefrontal and insular response to negatively valenced facial expressions in women at four to six weeks postpartum (Gingnell et al., 2015).

Throughout the postpartum period, increases in GMV have been reported in brain areas that partly overlap with the areas shown to undergo GMV reductions early postpartum, suggestive of partial recovery of GMV (Hoekezma et al., 2017; Hoekzema et al., 2022). Moreover, distinct activation in mothers has been shown in areas linked to emotion processing, such as the amygdala, prefrontal cortex, and insula (Parsons et al., 2017). Additionally, this increased activation has been shown to adapt with years of experience with motherhood, potentially reflecting a fine-tuning in neural pathways associated with caregiving (Parsons et al., 2017). Furthermore, number of childbirths are associated with younger brain age relative to nulliparous women in midlife and older age, with most prominent effects in brain areas implicated in motivation and maternal behavior (de Lange et al., 2019; de Lange et al., 2020; Voldsbekk et al., 2021). Brain age is the estimated age of the brain relative to chronological age based on machine learning calculations from various neuroimaging markers and is commonly used as an indicator of brain health where older brain age in adulthood is linked with negative health outcomes (Cole et al., 2018; Elliott et al., 2021). Moreover, a population-based study reported greater global GMV in parous women compared to nulliparous women decades following pregnancy (Aleknaviciute et al., 2022). Since GMV reductions in adulthood are associated with lower brain age (Hafkemeijer et al., 2014), these findings reflect distinct neural development, potentially resulting in a younger brain age in parous women.

Altogether, these findings demonstrate how the brain, and particularly neural circuits relevant to emotion processing continue to change beyond pregnancy and the postpartum period. Therefore, further understanding of the effect of parity on emotion processing is crucial to understand how pregnancy and motherhood affects neural activity. One way to further address the relationship between parity and emotion processing is by utilizing direct measures of electrocortical activity during emotion processing.

Electroencephalography

Electroencephalography (EEG) is a neuroimaging method widely used in research on cognitive and emotional processing (Citron, 2012; Hajcak et al., 2010; Schindler &

Bublatzky, 2020). EEG captures electrical activity from synchronized pyramidal cells, located in the cerebral cortex, instantaneously of firing. The signal is then captured in small electrodes located on the scalp that convey it to an amplifier allowing for further processing and analysis (Picton et al., 2000). Since the electrical signal must go through the scalp and other layers of tissue before it reaches the electrode, distortions and reduced spatial resolution represent challenges (Nunez et al., 1994). However, an advantage of EEG is that it is a noninvasive method that directly measures the neural signal from the region of interest with excellent temporal resolution of the neural event (Peterson et al., 1995). Event-related potentials (ERP) are commonly used measures in EEG research. ERPs are electrical potentials time-locked to an experimental event of interest and provide insights into the onset, latency, and trajectory of the neural signal (Picton et al., 2000). Numerous ERP components have been identified and linked with various aspects of cognition, ranging from lower to higher order processes (Picton et al., 2000). Although both types of neural processing are important in the context of emotion processing, later ERP components, i.e., from 300 ms post-stimulus presentation and beyond, are useful measures to understand higher-order processing of emotional content (Hajcak et al., 2010; Polich, 2007). Furthermore, given that some later presenting ERPs are modulated by emotional valence and arousal of perceptual stimuli, these components are of particular interest in research on emotion processing (Hajcak et al., 2010).

The Late Positive Potential

One ERP that is widely utilized in research on emotion processing is the late positive potential (LPP) (Hajcak & Foti, 2020). The LPP is a slow positively deflecting drift observed approximately 300 ms to 1000 ms following stimuli presentation, most prominently in the centro-parietal area, and commonly reported in the Cz, CPz and Pz recording cites (Hajcak & Foti, 2020). Previous studies aiming to localize the LPP have demonstrated a link between the component and several brain structures (Liu et al., 2012; Sabatinelli et al., 2006; Weidner et al., 2022). One study showed positive correlations during viewing of emotional pictures between within-individual ERP responses and blood-oxygen-level-dependent response in the lateral occipital cortex, parietal cortex, and the inferotemporal cortex (Sabatinelli et al., 2006). Moreover, by utilizing simultaneous fMRI and EEG recordings, Liu and colleagues (2012) extended these findings by demonstrating positive correlations with frontal and subcortical structures. For example, during viewing of pleasant images, positive correlations were detected between the LPP and activity in the bilateral occipital-temporal junctions,

temporal poles, precuneus, amygdala, medial prefrontal cortex, right nucleus accumbens, and cerebellum. Whereas, viewing of unpleasant images showed positive correlations in the left middle temporal cortex, temporal poles, left postcentral cortex, precuneus, bilateral ventral lateral prefrontal cortices, and bilateral insula. Additionally, a study from 2022 investigated amygdala intracranial local field potentials (iLFPs) from intracranial EEG recordings from one epileptic individual, that corresponded to LPPs from EEG recordings from a healthy sample (Weidner et al., 2022). The results from the iLFPs in response to voluntarily directing attention toward emotional images demonstrated that the amygdala is implicated in later processing of attended emotional stimuli. While the LPP has not been linked to a specific brain structure, taken together these findings imply a relationship between the LPP and structures involved in emotion processing.

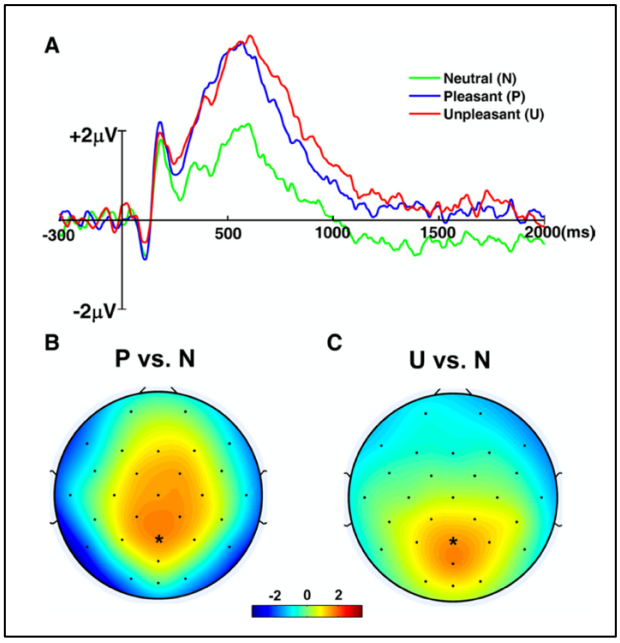
A further premise for linking the LPP with emotion processing is based on its modulation by the emotional and arousing content of the perceived stimuli. Previous research on the LPP has established that stimuli rated as emotional, both positively or negatively valenced, induced larger or more positive deflecting amplitudes compared to neutral stimuli (Cuthbert et al., 2000; Hajcak et al., 2010). For demonstration of this effect, see **Figure 1** (Liu et al., 2012). This effect has been demonstrated in response to various types of stimuli, e.g., image, sounds, and written text (Dunning & Hajcak, 2009; Gao et al., 2018; Gootjes et al., 2011). Moreover, during viewing of pleasant and unpleasant stimuli, amplitudes of the LPP are correlated with other autonomic measures associated with emotional reactivity such as skin conductance and heart rate further supporting its implication in emotion processing (Cuthbert et al., 2000) Additionally, arousing stimuli compared to non-arousing stimuli have demonstrated similar effects on LPP amplitudes as emotional valenced stimuli, were arousing stimuli elicits larger LPP amplitudes compared to non-arousing stimuli (Cuthbert et al., 2000).

The LPP has been implicated in emotion processing through automatic attention and top-down attentional allocation towards emotional stimuli (Hajcak et al., 2010). Previous findings have demonstrated that while LPP amplitudes were more positive during passive viewing of unpleasant stimuli compared to neutral stimuli, when participants were instructed to focus attention on neutral aspects of unpleasant images the LPP amplitude reduced significantly throughout the rest of the stimulus presentation (Dunning & Hajcak, 2009; Hajcak et al., 2009). This effect highlights how in addition to being modulated by passive bottom-up perception of emotional stimuli, the LPP is also modulated by higher order processes such as directed and sustained attention. Furthermore, emotion regulation strategies

have also been shown to affect LPP amplitudes. For example, smaller LPP amplitudes were elicited when participants were instructed to suppress emotions towards arousing images prior to stimulus presentation, compared to passive viewing and following instructions to enhance one´s own emotions towards the presented images (Moser et al., 2006). Smaller LPP amplitudes have also been demonstrated when neutral context is provided prior to presentation of arousing images (MacNamara et al., 2009). Further demonstrating how the LPP is both implicated in lower and higher order processing, the same study found components equivalent to early windows of the LPP (~ 300 ms) to be modulated by the image emotional content. In contrast, components equivalent to late LPP windows (~1000) were sensitive to context description (MacNamara et al., 2009). In view of the LPPs modulation during perception of emotional content and its modulation due to cognitive strategies, the LPP provides valuable insight on emotion processing.

Figure 1

Demonstration of the LPP



Note. A) Demonstration of grand average LPP at Pz recording cite in response to viewing neutral, pleasant, and unpleasant pictures (N = 11). B) Scalp distribution of the difference in LPP in response pleasant and neutral images (averaged across 300-800 ms). C) Scalp distribution of the difference in LPP in response unpleasant and neutral images (averaged across 300-800 ms). Figure from Y. Liu, 2012, Journal of Neuroscience, 32(42), 14563-14572, Figure 1, p. 14564, Copyright [2012] Society for Neuroscience.

The LPP and parity

Considering how LPP can be utilized in research on emotion processing, studying LPPs in parous vs. nulliparous women could shed a light on the relationship between emotion processing and parity. However, findings on the relationship between parity and the LPP are scarce (Vuoriainen et al., 2022). A meta-analysis from 2020 (Kuzava et al., 2020) found that parents of older children showed more positive LPP amplitudes in response to emotional infant expressions than parents of younger children. One study from 2014 compared ERPs including average amplitudes of the LPP in response to images of infants and adults showing facial expressions of either strong or mild intensity (Peltola et al., 2014). A comparison of 48 parous and 46 nulliparous women showed no differences between the groups in LPP amplitudes. However, mothers that performed more accurately when responding to negative infant expressions on an emotion recognition task showed more positive LPP amplitudes in response to positive infant expressions. In contrast, less accurate mothers had smaller positive amplitudes, and this effect was not present in nulliparous women (Peltola et al., 2014). Although these findings did not demonstrate a difference in LPP amplitudes dependent on parity status, the interaction between parity, LPP amplitudes, and emotion recognition are indicative of a relationship worthy of further exploration.

Despite the lack of research on the LPP and parity, differences between parous and nulliparous women have been shown in other ERPs. For example, the P300, which reminiscent to the LPP (Polich, 2007), is a positively deflecting drift observed approximately 200 ms post stimuli presentation and is also modulated by stimulus emotional valence (Hajcak & Foti, 2020). Because of the similarities between the LPP and P300, Hajcak and Foti (2020) argued that the two components may represent the same underlying neural mechanism. Considering these similarities, it is worth noting that one study demonstrated larger P300 amplitude in response to emotionally valenced images of unfamiliar infants in postpartum mothers compared to fathers and nulliparous women (Proverbio et al., 2006). This effect was especially prominent in response to negative images. Furthermore, in women postpartum, the P300 has been shown to be increased in primiparous women compared to multiparous women in response to infant cries and facial expressions regardless of if the expressions were emotional (Maupin et al., 2019). Authors of the study proposed that the differences in the P300 may reflect heightened anxiety toward infant related stimuli in first time mothers. Taken together these findings illustrate that there are not only potential differences in later ERPs in parous and nulliparous women, but also differences within the parous group.

Some earlier ERP components, that occur within the first milliseconds of stimulus presentation and are associated with bottom-up cognitive processes (Sokhadze et al., 2017), have also been found to be different in mothers compared to nulliparous women (Noll et al., 2012; Peltola et al., 2014; Proverbio et al., 2006). For example, in Peltola et al. (2014) the peak amplitude of the N1 component was faster in response to intense infant facial expressions compared to neutral expressions in parous compared to nulliparous women (Peltola et al., 2014). Similarly, another study found increased N1 amplitudes in response to infant cries and sounds unrelated to infants in postpartum mothers (Purhonen et al., 2008). In Proverbio et al (2006), the P1 amplitude in the left hemisphere was larger in mothers than non-mothers in response to images of infants' facial expressions regardless of emotional valence. The N1 and P1 components are associated with early attentional processes such as attention allocation and orientation (Sokhadze et al., 2017). Hence increased amplitudes and faster latencies of the N1 and P1 may indicate increased alertness in motherhood. Furthermore, mothers showed greater earlier posterior negativity (EPN; ~ 240 ms post-stimulus presentation) in response to negative infant facial expressions (Peltola et al., 2014). This EPN component is believed to reflect identification of emotional content within a stimulus (Schupp et al., 2003). Peltola and colleagues (2014) proposed that this pattern of the EPN reflected a more empathic response to infant faces in parous compared to nulliparous women. In line with this, mothers, and fathers, compared to non-parents, showed greater distinction in the N2 component, a component linked to error detection (Sokhadze et al., 2017), in response to images of infants depicting negative facial expressions of different intensities. However, whether the differences in parents and non-parents are attributable to pregnancy-induced neuroplasticity specific to mothers or experience dependent plasticity resulting from caretaking are not clear. Nonetheless, the differences found between parents and non-parents, in addition to the differences between biological mothers and fathers, suggest an interaction between both environmental and biological factors.

The LPP and confounding variables

Psychological, social and biological factors have been shown to affect how the LPP is modulated by emotional stimuli, hence accounting for these factors is crucial for an accurate understanding of the LPP. For instance, research on parous and pregnant women has demonstrated a link between the LPP and peripartum mental health (Mulligan et al., 2022; Rutherford et al., 2018). To demonstrate this, greater LPP amplitudes in response to neutral infant stimuli was associated with increased anxiety symptoms postpartum (Mulligan et al.,

2022; Rutherford et al., 2018). Furthermore, during late pregnancy, the same pattern of the LPP predicted increased difficulties for mothers understanding and identifying their own infants' emotions and needs postpartum (Rutherford et al., 2018). In women postpartum, one study demonstrated that perceived social support modulated LPP amplitudes in response to neutral infant stimuli (Nyman et al., 2020). In their study, Nyman and colleagues reported a link between perception of less social support with larger LPP amplitudes in response to neutral images, resulting in reduced distinction between neutrally and emotionally valanced stimuli. Moreover, another study found that neglectful compared to non-neglectful mothers showed attenuated LPP response when presented with negative infant stimuli, demonstrating a reduction in the traditional LPP response (Rodrigo et al., 2011).

Although not specific to parous women, amplitudes of the LPP have also been shown to be greater in individuals with general anxiety disorder (GAD) compared to healthy controls when presented with emotional images (MacNamara & Hajcak, 2010; Richards et al., 2013). Moreover, individuals with a GAD diagnosis showed larger LPP amplitude when presented with unpleasant images during a task requiring increased working-memory load, where as increased working memory load reduced the emotional modulation in healthy controls (Schupp et al., 2003). In addition to a link between GAD and the LPP, trait worry has been shown to be correlated with LPP amplitutes, where increased worry was linked with larger LPP amplitudes in response to emotional images, and this effect was present when controlled for anxiety symptoms (Burkhouse et al., 2015). In contrast, previous findings have shown reduced LPP amplitudes in response to emotional and arousing stimuli in individuals with depressive symptoms and depressive disorders, resulting in smaller differences between emotionally valenced compared to neutral stimuli. (Foti et al., 2010; Klawohn et al., 2021; Weinberg et al., 2016; Weinberg & Sandre, 2018). However, a recent study could only replicate this effect in one out of 28 exploratory analyses using different analysis pipelines and parameters previously reported in the literature (Nikolin et al., 2022). Therefore, more research on the effect of depression on the LPP is warranted.

In addition to an association between mental health and the LPP, reduced sleep is linked with larger LPP amplitudes in response to emotionally valenced stimuli (Cote et al., 2015). For example, in sleep deprived compared to non-sleep deprived individuals, Cote et al. (2015) found larger LPP amplitudes in response to emotionally valenced stimuli and no difference between the groups for neutral stimuli. In opposition to Cote et al (2015), Alfarra et al., (2015) found increased LPP amplitudes in response to neutral images, and this effect resulted in reduced distinction between emotional and neutral stimuli in the LPP component.

Another study linked sleep deprivation with greater difference between positive and neutral stimuli compared to the difference between negative and neutral stimuli, suggestive of an increased attention towards positive stimuli in a sleep deprived state (Lustig et al., 2018). Despite inconsistent findings, the effect of sleep on the LPP highlights the importance to account for sleep when researching the LPP.

Furthermore, LPP amplitudes in response to emotional and arousing stimuli have been associated with sex hormone levels in women (Munk et al., 2018, 2020; Lusk et al., 2015, 2017, Monciunskaite et al., 2019) and menstrual cycle phase (Zhang et al., 2013). For example, increased levels of estradiol during the follicular and ovulatory phase have been shown to be positively correlated with larger LPP amplitudes in response to words containing arousing content compared to neutral content (Munk et al., 2018). In contrast, Munk et al. (2020) found that during ovulation LPP amplitudes in response to arousing images were negatively correlated with estradiol levels. Furthermore, women using oral contraceptives, where endogenous sex hormone levels are lower (Fleischman et al., 2010), showed a blunted LPP in response to neutral and unpleasant images compared to naturally cycling women (Monciunskaite et al., 2019). In addition, increased levels of oxytocin have been shown to enhance LPP amplitudes in women when presented with emotionally valenced stimuli (Huffmeijer et al., 2013), Therefore, considering hormonal differences between parous and nulliparous women (Barrett et al., 2014; Dorgan et al., 1995), and increased levels of oxytocin in women postpartum (Levine et al., 2007) differences may be present in the LPP between parous and nulliparous women.

Aims and hypothesis of the present study

The aim of the present study was to investigate emotion processing in parous and nulliparous women.

H1: LPP amplitudes will vary as a function of stimulus valence (manipulation check)

The LPP has been shown to be modulated by emotional valence (Cuthbert et al., 2000; Hajcak et al., 2010a). Hence, the first hypothesis (H1) of the study was that LPP amplitudes would be more positive in response to emotionally valenced images, i.e., positive, and negative, compared to neutrally valenced images.

H2: The effect of stimulus valence on LPP amplitudes will vary as a function of parity

The second hypothesis (H2) of the study was that parity would interact with the main effect of emotion valence on the LPP amplitudes. Specifically, that parous women would differentiate more in LPP amplitudes between the emotion valence conditions than

nulliparous women. Although these hypotheses contradict previous finding from Peltola et al. (2014) where no interactions between emotion valence and parity was detected on the LPP, increases in the LPP were expected in respect of the trend in the literature indicating a stronger response to emotional stimuli in parous women.

H3: There will be a larger difference between LPP in response to emotional and neutral images in parous compared to nulliparous women

In line with H2, the third hypothesis (H3) was that within-individual difference between LPP amplitudes in response to emotionally valenced and neutral stimuli would be larger in the parous group compared to the nulliparous group. This effect was expected for both for the difference between LPP in response to positive and neutral images, and in the difference between LPP in response to negative and neutral images.

H4: LPP reactivity will vary as a function of anxiety symptoms, depression symptoms and sleep quality.

To further investigate potentially confounding variables and how they may affect emotion reactivity, relationship between depression and anxiety symptoms and sleep quality and the difference scores between the LPP emotional and neutral images was investigated. A positive relationship was expected between anxiety and depression symptoms and, the difference between LPP in response to emotion and neutral images. However, a negative relationship was expected between sleep quality and the difference between LPP in response to emotion and neutral images.

Exploratory analysis: LPP reactivity will vary as a function of parity-related variables

Finally, potential relationship between variables specific to the parous sample with the reactivity scores was explored. The variable included in the analysis were years since last childbirth and age at last childbirth. This analysis was exploratory.

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Methods

Sample

The sample of the present study is a subsample of the ERC-funded research project BRAINMINT: *Brains and Minds in transition* (PI Lars T. Westlye), carried out at the Department of Psychology, University of Oslo, Norwegian Centre for Mental Disorders Research (NORMENT), and the Oslo University Hospital (OUS),

https://www.sv.uio.no/psi/forskning/prosjekter/brainmint/om-prosjektet/index.html. The aims of the BRAINMINT project are to investigate mental disorders during neuroplastic periods, specifically pregnancy and adolescence. The pregnancy study within BRAINMINT is a longitudinal study and collects neuroimaging and questionnaire data from women before, during, and after pregnancy. Data collection started in October of 2020 and is still ongoing. In the present study, all participants in the BRAINMINT pregnancy study that had completed EEG and questionnaires at the preconception timepoint were eligible for inclusion. The sample started of with 240 women over the age of 18 that had completed the EEG and questionnaires. Due to missing data, bad EEG quality, low accuracy on behavior task, history of severe mental disorders and other reasons, 19 participants were excluded from the sample (for details see results, sample characteristics). Therefore, a total of 221 women was included and split into two groups based on parity status (parous and nulliparous). The nulliparous group consisted of 143 women, and the parous group consisted of 78 women (mean age = 33.35, SD = 3.43). In the parous group, 71 women were primiparous (mean age = 31.16, SD = 3.26) and 7 were multiparous. Exclusion criteria for the study was current and/or prior history of severe mental illness and less than 30% accuracy on the computerized task. For a detailed overview of the sample's demographics and participant exclusion, see the results section “Sample characteristics”. All participants provided informed consent prior to participating in the study. Participants were not reimbursed for participation and were informed that they could withdraw from participation at any timepoint.

Procedure

Participants were recruited using online advertisements. After signing up for the research project, participants were sent a link via email to online questionnaires (Nettskjema.no). The questionnaires included questions on demographic information and mental health measures. The EEG sessions took place at an EEG laboratory at the University of Oslo. During each session, participants completed a total of six computerized cognitive tasks, at 80 cm distance from the computer screen. Each session was approximately three hours and included explaining the procedure of the EEG session and tasks, setting up the EEG equipment, and performing the tasks. The duration of each recording was approximately two hours. The emotional reactivity task used in the present study was the final task of the recording session, see section “Task paradigm and stimuli” for detailed description of the task. Before starting the task, participants received instructions from research technicians and

went through a practice round to ensure participants fully understood the task. Following the test run, participants went through the task which took approximately five minutes.

Task paradigm and stimuli

The emotional interrupt task consisted of a presentation of emotionally valenced images on a computer screen and a response time-accuracy task. The task was similar to tasks used in Weinberg and Hajack (2011) and Mulligan and colleagues (2022) and was included to ensure that participants attended the images presented on the screen. Participants with accuracy below 30% were excluded from the study. Images of scenes containing children and adults that have previously been rated as positive, negative, or neutral were presented for one second one at a time on a computer screen. All images used in the task were from the EmoPics photobank (Wessa et al., 2010), The Geneva Affective Picture Database (GAPED; Dan-Glauser & Scherer, 2011), EmoMadrid (Carretié et al., 2019), Open Affective Standardized Image Set (OASIS; Kurdi et al., 2017) and Nencki Affective Picture System (NAPS; Marchewka et al., 2014). See Appendix for complete overview of images used in the task. Positive and negative images were matched on arousal ratings, whereas neutral images had lower arousal ratings. For the practice round, participants responded to nine images. In the task, participants responded to 90 images, 30 were positive (mean positivity rating: 1.164), 30 negative (mean valence rating: - 1.955) and 30 neutral (mean valence rating: -0.153). The valence ratings provided were based on z scores that were calculated from the valence scores provided for each image across the photo corpora included. The z scores are on a continuous scale and range from -2.53 (most negative) to 1.6 (most positive). For the positive and negative conditions, 15 images were of adults and 15 were of children (some included children with adults). For the neutral condition, all pictures included adults, except one included a child. Some images included one individual in the image, whereas others included two or more people, see **Figure 2** for examples of images used in the task. First, an image was presented on the screen for 1000 ms, followed by an arrow on the middle of the screen for 150 ms, pointing either to the left or to the right. As the arrow appeared on the screen, participants were instructed to press with their thumbs on one of two buttons on a response pad corresponding to the arrow's direction. After pressing the button as quickly and accurately as possible, the same image as before the arrow was presented again for 0.450 seconds. Following the second picture presentation a fixation cross appeared on the middle of the screen for 0.775 seconds and was followed by the next picture to be presented. See **Figure 3** for a visual description of the task paradigm.

Figure 2

Examples of images presented in the task for each valence of children and adults.

Note. Overview of pictures and corresponding photobanks in the figure. Top panel, from left to right: “EMO 376” (EmoMadrid), “School 2” (OASIS), “93” (EmoPics). Bottom panel, from left to right: “224” (EmoPics), Emo708” (EmoMadrid), “105” (EmoPics).

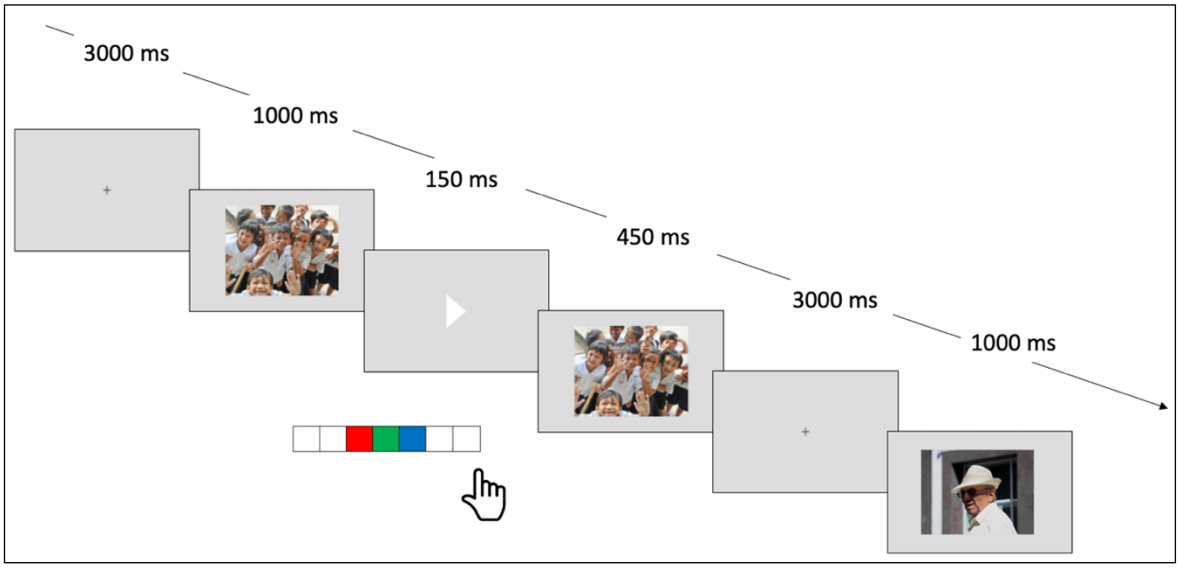
Questionnaires

General Anxiety Disorder (GAD)-7

The GAD-7 scale is a seven-item self-report scale developed by Spritzer et al. (2006) to screen for symptoms of generalized anxiety disorder in the past two weeks. Each item on the scale ranges from 0 (symptom not present) to 3 (symptom present nearly every day). The scale measures the severity of anxiety symptoms and the presence of symptoms. The outcome measure of the scale is a sum score of each symptom's severity, resulting in outcome scores ranging from 0 - 21. Recommended interpretation of the scale is minimal (0–4), mild (5–9), moderate (10–14), and severe (15–21) anxiety levels (Spritzer et al., 2006; Plummer et al., 2016). A recommended cut-off score for indication of generalized anxiety disorder is from 8-10. The GAD-7 scale has demonstrated acceptable validity and reliability as a measure of anxiety symptoms (Spritzer et al., 2006; Plummer et al., 2016).

Figure 3

Visual demonstration of the task paradigm for the emotional reactivity task.



Note. Pictures and corresponding photobanks included in figure from left to right: "School 2" (OASIS) and "Faces 182 h" (NAPS). The white and colored squares represent the buttons on the response pad. Only the white square to the far left and right were used in the task, the other buttons on the response pad were used in other tasks during the EEG recording.

Edinburgh Postnatal Depression Scale (EPDS)

The EPDS is a ten-item self-report scale developed to screen for postnatal depression (Cox et al., 1987). Each item on the scale is scored on a four-point Likert scale ranging from 0 to 3, resulting in a maximum sum score of 30 points. A higher sum score indicates a more severe level of depression. Authors of the scale suggest that a sum score of 12-13 indicates clinical depression. Validity, sensitivity, and reliability of the EDPS as a measure of depression have been demonstrated as acceptable in both postnatal samples (Cox et al., 1987; Eberhard-Gran et al., 2001) and other populations, including non-postnatal (Cox et al., 1996) and pregnant women (Rubertsson et al., 2011).

Perceived Stress Scale (PSS)

The PSS is a 10-item self-report questionnaire used to measure an individual's perception of stress over the past month (Cohen et al., 1988). The PSS-10 is an updated version of the original PSS scale which included 14 items (Cohen et al., 1988). The scale is on a four-point Likert scale ranging from 0 (item not present) to 3 (item present very often), resulting in sum scores ranging from 0 to 40. A higher sum score on the scale indicates

greater perceived stress. The PSS-10 scale has been shown to have considerable reliability and validity, and greater internal reliability than its precursor (Cohen et al., 1988).

Pittsburgh Sleep Quality Index (PSQI)

The PSQI is a self-report questionnaire developed to measure sleep quality and disturbances (Buysse et al., 1989). PSQI consists of 19 questions divided into seven sleep quality components. The seven components of the PSQI are sleep latency, duration, disturbances, subjective sleep quality, habitual sleep efficiency, use of sleeping medications, and daytime dysfunction. Scores for each component range from 0-3. To calculate a global score, total scores from each component are summed together, resulting in a global score ranging from 0-21 (Buysse et al., 1989). The global score of PSQI has been shown to be sensitive to discriminate between good and bad sleep quality (Buysse, 1989). In addition, the global score has been shown to have acceptable construct reliability and internal consistency (Carpenter & Andrykowski, 1998; Mollayeva et al., 2016).

EEG data acquisition

A 64-channel BioSemi ActiveTwo amplifier was used for the EEG recordings, along with AG-AGCl sintered electrodes. Distribution of the cap electrodes across the scalp was in accordance with the international 10-5 system, using 64 scalp electrodes. Electrode offset was maintained between 20 and -20 mV. To measure horizontal eye movements (electrooculogram; EOG) two external electrodes were placed approximately 1 cm left to the left eye and right to the right eye. Additionally, external electrodes were placed on the left iliac crest and right clavicle (measuring the electrocardiogram, ECG), and two electrodes on the left and right abductor pollicis brevis (measuring electromyographic activity related to manual responses). To minimize common mode voltages, a driven right-leg electrode was used.

EEG data processing

EEG signal processing was carried out using MATLAB version R2020a (Mathworks, 2020) and the EEGLAB toolbox version 2019b (Delorme & Makeig, 2004). Before preprocessing was performed, the data was down sampled to 512 Hz. In addition, the datasets from the emotional reactivity task were concatenated with two five-minute resting state datasets from the same recording session to provide more data for the independent component analysis (ICA). The PREP preprocessing pipeline was applied to the concatenated datasets to clean the data prior to further processing (Bigdely-Shamlo et al., 2015). The main steps of the PREP pipeline are line-noise removal, computation of a robust reference of the

signal that is relative to an estimate of the "true" average reference, identification of bad channels, and interpolation said channels in accordance with the robust average reference. A unique feature of the PREP pipeline is that line-noise removal is performed without filtering the data beforehand, allowing for more flexibility in filter choice later in the data processing. To filter the data, the high-pass filter was set to 0.01 Hz and low-pass filter was set to 100 Hz. Filter settings were decided in respect to previous research on the LPP (Coll, 2018; Klawohn et al., 2020), in addition to adhering to recommendations of using minimal filtering to reduce signal distortion (Holinger et al., 2000; Luck et al., 2014, p. 245). Next, ICA was performed to decompose the data and classify common artifacts, brain-related or other using the ICLabel automated classifier, which assigns probability estimates to each class (Pion-Tonachini et al., 2019). Independent components that were estimated at less than 20% probability to reflect brain activity and more than 40% probability of reflecting "other" components were rejected. After ICA, the continuous data was extracted into epochs time-locked -0.2 to 2 seconds to the stimuli presentation. Finally, the EEG data was re-referenced to the average of P9 and P10, electrodes located close to the mastoid processes and quantified the LPP in response to positive, neutral, and negative images as average amplitudes across all trials that survived epoch rejection for each image type across the Cz, CPz, Pz, CP1 and CP2 recording cites. Quality control for the EEG data was performed with visual inspection of the data for each participant, both continuous data from all channels and the epoched data were inspected.

Statistical Analysis

All statistical analysis were performed using R, version 4.1.2. (R Core Team, 2021) and Rstudio version 2021b (RStudio Team, 2021b), plots (RStudio Team, 2021b) for data visualization were created using R (R Core Team, 2021), RStudio (RStudio Team, 2021b) and EEGlab version 2019b (Delorme & Makeig, 2004). Any assumptions for the statistical analysis method that were not met are addressed in the result section.

Questionnaires

Independent t-tests were performed to investigate group differences on questionnaire measures, and Cohen´s d was used to test effect-sizes. To calculate the Cohen´s d, the R package Effectsize (Ben-Shachar et al., 2020) was used, to divide the difference between the means of the two groups (parous and nulliparous) by the pooled standard deviation (Cohen, 1988, p.27).

H1 and H2: Average LPP amplitudes

A repeated measures stimulus valence (three levels: positive, negative, and neutral) by parity (two levels: parous, nulliparous) analysis of variance (ANOVA) was run to investigate the effect of viewing positively, negatively, and neutrally valenced images on LPP amplitudes and to investigate the effect of parity status. The dependent variable was specified as the average LPP amplitudes, the within-subject factor was specified as image type, i.e., positively, negatively, and neutrally valenced images, and the between-subject factor was parity status, i.e., parous, and nulliparous. To control for possible group differences on demographic factors and the questionnaire measures, a follow-up ANCOVA was performed, including the demographics and questionnaires that differed between the groups as covariates. To control for noise in the EEG data, the standard error of the mean (SEM) of the LPP amplitudes for each participant was calculated and included as a covariate as a quantitative quality metric in an additional follow-up ANCOVA (Luck et al., 2020). To further test the robustness of the ANOVA, two separate sensitivity analysis were performed. For the first sensitivity analysis, 21 participants were excluded from the ANOVA due to history of mental disorders that other than anxiety, depression, and severe mental disorders. The mental disorders were not specified, therefore the participants were excluded from the sensitivity analysis. For the second sensitivity analysis, one participant with less-than-ideal EEG data quality was excluded from the ANOVA. Effect sizes for the 2x3 repeated ANOVA, follow-up ANCOVAs and sensitivity analyses were estimated with partial eta squared.

H3: Reactivity scores and parity

Two reactivity scores were calculated for a within-individual comparison of the LPP amplitudes in response to emotional and neutral images. The reactivity scores were calculated as “positive reactivity” = “LPP in response to positive images” – “LPP in response to neutral images”, and “negative reactivity” = “LPP in response to negative images” – “LPP in response to neutral images”. Average reactivity scores across the groups were then compared with independent t-tests.

For a more comprehensive comparison of the reactivity score between the groups, a repeated measures parity (two levels: parous, nulliparous) by valence (two levels: positive reactivity, negative reactivity) ANOVA was performed, with valence of reactivity score specified as within-subject factor, and parity status specified as between subject-factor. Additionally, two follow-up ANCOVAs were performed. The former ANCOVA included questionnaire and demographic measures that differed between the groups as covariates. The

covariates included were age and PSQI global score. The latter ANCOVA included the SEM of the LPP amplitudes as a covariate. Next, two sensitivity analysis were performed, first excluding 21 participants from the ANOVA with history of mental disorders other than anxiety, depression, and severe mental disorders. Second, one participant was excluded from the ANOVA due to less-than-ideal quality of EEG data. To estimate the effect sizes for the 2x2 repeated measures ANOVA, the follow-up ANCOVAs and sensitivity analysis, partial eta squared was calculated for each model.

H4: Reactivity scores and mental health

To examine relationships between the reactivity scores and the questionnaire measures, two multiple linear regression models were fitted. First a multiple linear regression was performed with the response variable specified as positive reactivity score, and the predictor variables specified as age, parity status, EPDS sum score, GAD sum score, and PSQI global score. For the second model, the response variable was specified as the negative reactivity score and the predictor variables were the same as included in the first regression model. Because of the assumption of multicollinearity between predictor variables (Osborne & Waters, 2019) and the presence of high correlations between PSS and GAD sum scores, PSS scores were not included in the model.

H4: Exploratory analysis

To examine relationships with factors specific to parity two linear regression models were performed on the parous group. For the first model, the response variable was specified as positive reactivity scores and the predictor variables were years since last birth, and age at first birth. The second regression model included the same predictor variables, and the response variables was specified as negative reactivity scores.

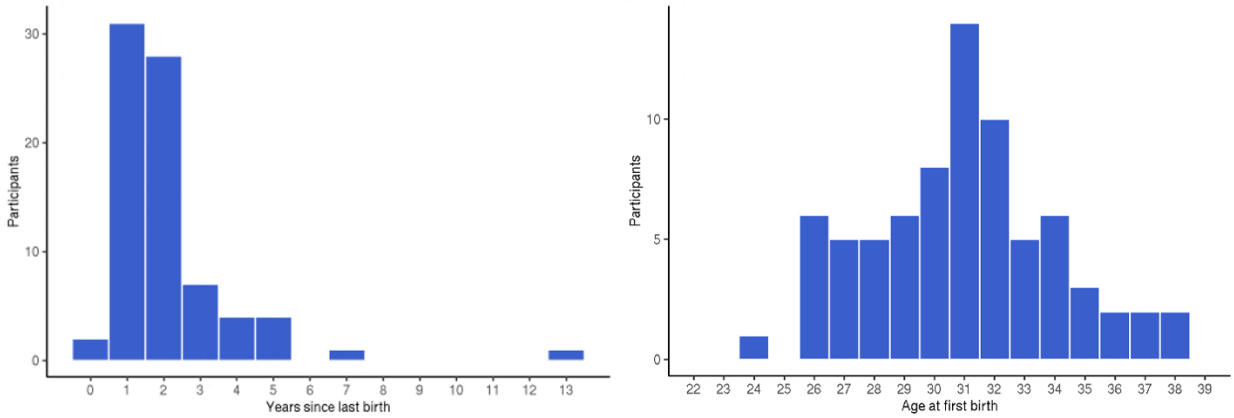
Results

Sample characteristics

A total of 19 participants were excluded from the study; two were excluded due to a history of severe mental illness, two due to technical issues during the EEG recording, six were excluded during preprocessing due to technical issues with the EEG files, three were excluded due to missing data from the response task, one was excluded due to low accuracy on response task (0%) and five were excluded for other reasons (pregnant/unexplained). The final sample consisted of 221 participants, with 78 women in the parous group and 143 in the

nulliparous group. In the parous group, 71 women were primiparous, and seven women were multiparous, see **Figure 4** for distribution of years since last childbirth and age at first childbirth. The groups differed in age and global score on the PSQI scale, with higher age and lower mean global score on the PSQI in the parous group. Demographic information and frequency of anxiety and depression were similar between the groups, see Table 1 for results from chi-square and t-tests for demographic information and questionnaire responses.

Figure 4
Distribution of years since last birth in parous participants and age at first birth.



Behavioral data

For averages and standard deviations of the reaction times in response to each emotional valence on the emotion response task see Table 2. A 2x3 ANOVA comparing the response times across parity status and emotional valence was not significant, across neither parity $F(1,219) = 0.221$, $p = 0.638$,), $\eta^2_{partial} < 0.001$, nor emotion valence $F(2,438) = 1.062$, $p = 0.347$,), $\eta^2_{partial} < 0.001$. There was also not a significant interaction between parity and emotion valence $F(2,438)=1.130$, $p = 0.324$, $\eta^2_{partial} < 0.001$. See **Figure 5** for distribution of accurate response across the 90 trials on the response task.

EEG results

See Table 2 for average number of trials after epoch rejection and standard deviations across the groups and emotion valences. As a quality estimate of the LPP amplitudes, the standard error of the mean (SEM) was calculated. The average SEMs across all conditions and for each condition were compared between the groups using t-tests. See Table 2 for descriptive statistics and t-test results for the SEM of the LPP amplitudes.

Table 1

Descriptive statistics for demographic variables, history of mental disorders and questionnaires.

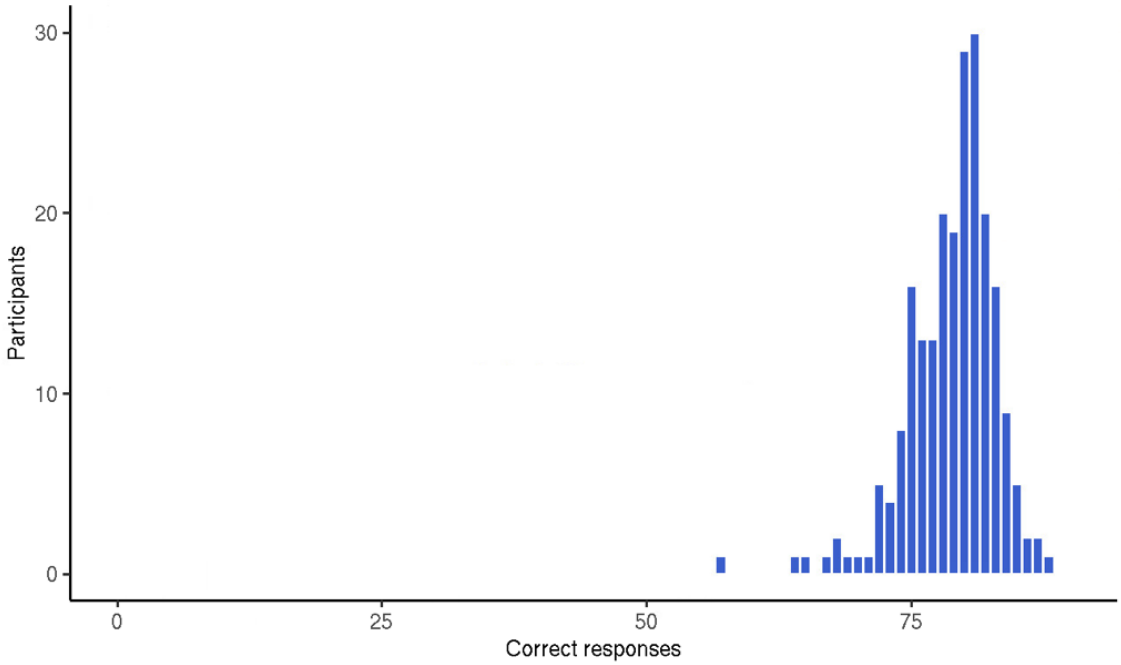
	Parous (N = 78)	**Nulliparous (N = 143)**	**Overall (N= 221)**			
Chi-square	**%**	**%**	**%**	**df**	**χ^2**	**p-value**
Anxiety	28.2%	32.2%	30.8%	1	0.20928	0.6473
Depression	28.2%	34.3%	32.1%	1	0.59495	0.4405
Other mental disorders	11.5%	8.4%	9.5%	1	0.27286	0.6014
Educational level						
Secondary/ vocational school	2.5%	2.8%	2.7%	1	9.0373e-31	1.000
University/ training college (1 to 3 years)	17.9%	25.9%	23.1%	1	1.3673	0.2423
University/ training college (4 or more years)	7%	76.9%	73.8%	1	0.90327	0.3419
Work status						
Full-time	89.7%	90.2%	90.0%	1	1.6699e-30	1.000
Part-time	5.1%	7.7%	6.8%	1	0.1975	0.6567
Student	3.8%	8.4%	6.8%	1	1.0081	0.3154
Other	10.3%	8.2%	8.6%	1	0.06976	0.7917
Relationship status						
Relationship	100%	97.9%	98.7%	1	0.46208	0.4967
Single	-	2.1%	1.3%	1	0.46208	0.4967

T-tests	**Mean**	**SD**	**Mean**	**SD**	**df**	**t-value**	**p-value**	**Cohens' d**
Age	33.52	3.43	31.16	3.26	219	-4.6947	4.70e-06***	-0.66
EPDS	4.35	3.57	4.73	4.14	219	0.66246	0.5084	0.09
GAD	4.36	2.78	4.65	3.66	219	0.61335	0.5403	0.09
PSS	13.81	5.87	13.95	5.44	219	0.18206	0.8557	0.03
PSQI	7.53	2.24	6.44	2.13	219	-3.5568	0.0005***	-0.50

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Figure 5

Correct responses in the response task out of 90 trials.



H1 and H2: Parity x emotion valence repeated measures ANOVA for LPP amplitudes

Grand average LPPs for the parous and nulliparous group are presented in **Figure 6**, and averages and standard deviations are presented in Table 2. Mauchly´s sphericity test showed that the ANOVA violated the assumption of sphericity, $\chi^2(2)=0.972$, $p = 0.462$, and the Greenhouse-Geisser epsilon was > 0.75, therefore Huynh-Feldt correction was applied to the ANOVA (Huynh & Feldt, 1976; Mauchly, 1940).The 2 (parity) x 3 (emotion valence) ANOVA showed highly significant main effect of emotion valence $F(2,438) = 419.376$, $p =$ 1.201479e-100, $\eta^2_{partial} = 0.66$, as well as a significant interaction between emotion valence and parity $F(2,438) = 3.493$, $p = 0.0321$, $\eta^2_{partial} = 0.02$. The main effect of parity was not significant $F(1, 219) = 0.007$, $p = 0.934$, $\eta^2_{partial} < 0.001$. See **Figure 7** for visualization of the interaction between parity and emotion valence. For post hoc analysis, pairwise comparisons with Bonferroni correction were performed. The pairwise comparisons showed significant difference for all emotional valences, between positive and neutral images $p <$ 2e-16, between negative and neutral images $p <$ 2e-16, and between positive and negative image types $p <$ 1.3e-05. In both groups, average LPP amplitudes were more positive in response to positive than neutral images, and more positive in response to negative than positive images.

For the sensitivity analysis that excluded participants with history of mental disorders other than anxiety, depression, and severe mental disorders, 21 participants were excluded.

The analysis resulted in a sample of 200 participants with 69 in the parous group and 131 in the nulliparous group. The results of sensitivity analysis were consistent with the main ANOVA for LPP amplitudes, see Table 1 in the Appendix. For the sensitivity analysis that excluded participants with less-than-ideal EEG data quality, one participant was excluded and was nulliparous. This analysis resulted in a sample of 220 participants with 78 in the parous group and 143 in the nulliparous group. The analysis also replicated the results from the main ANOVA for the LPP amplitudes, see Table 1 in the Appendix.

Follow-up analysis: Parity x emotion valence repeated measures ANOCOVAs for LPP amplitudes

Two follow-up analyses were performed on the 2x3 repeated measures ANOVA to investigate effects of the cofounding variables that differed significantly between the groups and to adjust for differences in the standard error mean of the LPP amplitudes between the group. After adjusting for age and PSQI global score the 2x3 ANCOVA showed a highly significant main effect of emotion valence $F(2,434) = 424.467$, $p < 2e\text{-}16$, $\eta^2_{partial} = 0.66$, and a significant effect of age $F(1,217) = 323.5$, $p = 0.00576$, $\eta^2_{partial} = 0.03$. No main effects were for parity $F(1,217) = 0.007$, $p = 0.93286$, $\eta^2_{partial} < 0.001$ and PSQI global score $F(1,217) = 1.862$, $p = 0.17383$, $\eta^2_{partial} < 0.001$. The model also showed a significant interaction effect between emotion valence and parity $F(2,434) = 3.536$, $p < 0.0300$, $\eta^2_{partial} = 0.02$, a trend towards significant interaction between emotion valence and age $F(2,434) = 2.475$, $p = 0.0854$, $\eta^2_{partial} = 0.01$, and no interaction between emotion valence and PSQI global score $F(2,434) = 2.184$, $p < 0.1139$, $\eta^2_{partial} < 0.001$. After adjusting for standard error of the mean of the LPP amplitudes, the 2x3 ANCOVA showed highly significant main effect of emotion valence $F(2,438)= 419.376$, $p < 2e\text{-}16$, $\eta^2_{partial} = 0.66$ and significant interaction effect between emotion valence and parity $F(2,438)=3.493$, $p < 0.0313$, $\eta^2_{partial} = 0.02$. The model showed no main effect of parity $F(1,218)=0.007$, $p = 0.934$, $\eta^2_{partial} < 0.001$, and no main effect of the standard error of the mean $F(1,218)=1.978$, $p = 0.161$, $\eta^2_{partial} = 0.01$.

Table 2

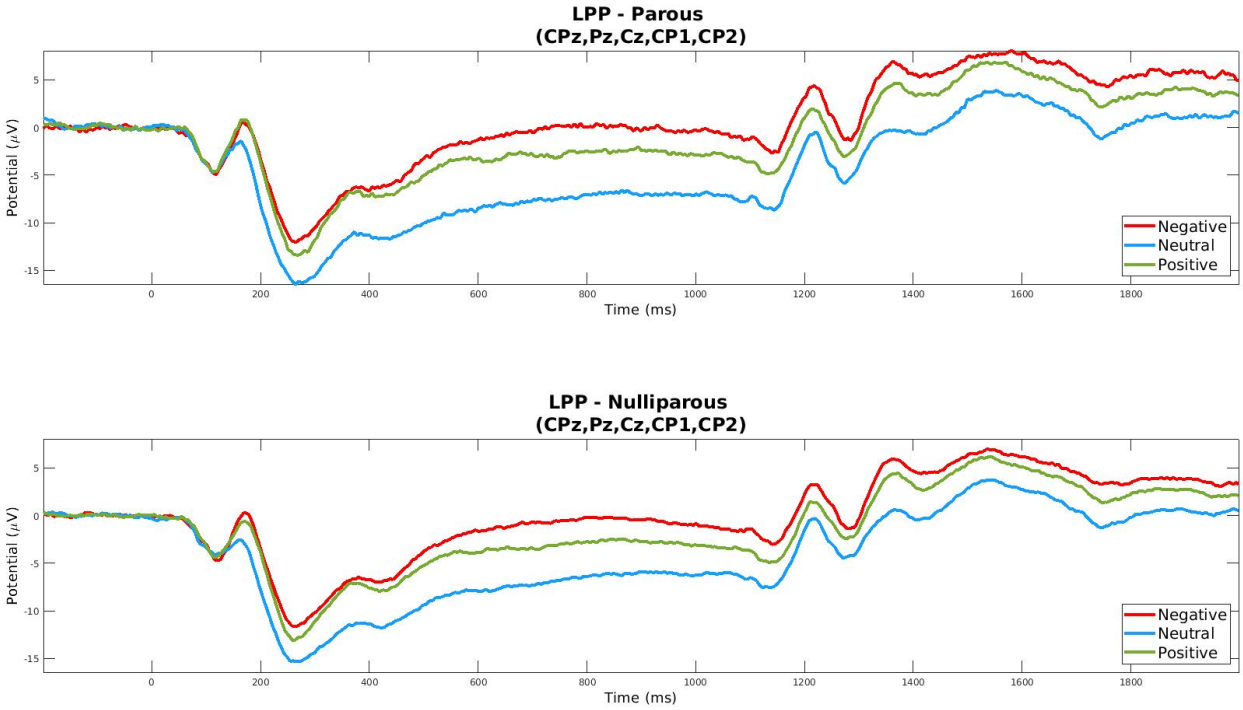
Means, standard deviations and t-tests for response time, SEM, and number of trials after epoch rejection.

	Parous		Nulliparous		t – test			
	Mean	SD	Mean	SD	t-value	df	p-value	Cohens`d
LPP amplitudes								
Negative	-2.32	4.82	-2.69	4.69	-0.56532	219	0.5724	-0.08
Positive	-4.28	3.88	-4.49	3.64	-0.39327	219	0.6945	-0.06
Neutral	-9.03	4.21	-8.32	4.03	1.2418	219	0.2157	0.17
Response time								
Negative	0.41	0.06	0.42	0.06	0.31397	219	0.87538	0.04
Positive	0.41	0.06	0.42	0.06	1.0621	219	0.2894	0.15
Neutral	0.42	0.06	0.42	0.06	-0.00242	219	0.9981	-0.01
LPP SEM								
Negative	2.03	0.58	1.85	0.48	-2.38	219	0.01802*	-0.34
Positive	1.98	0.58	1.81	0.48	-2.31	219	0.02161*	-0.33
Neutral	1.94	0.51	1.80	0.49	-1.9686	219	0.05026*	-0.28
Overall	1.98	0.50	1.82	0.44	-2.4753	219	0.01407*	-0.35
Number of trials								
Negative	28.53	2.89	29.16	1.51	2.1478	219	0.03283*	0.30
Positive	28.63	2.40	29.09	1.64	1.7215	219	0.08658	0.24
Neutral	28.76	2.10	29.15	1.55	1.5761	219	0.1164	0.22

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Figure 6

Grand average LPP amplitudes across all emotion valences in both groups.



H3: t-tests and parity x emotion valence repeated measures ANOVA for reactivity scores

Independent t-tests showed significant differences between the positive reactivity and negative reactivity scores between the groups, with higher scores in the parous group. See Table 3 for means, standard deviations, and t-tests for the reactivity scores and **Figure 8** for visualization of the reactivity scores. In both groups, the negative reactivity scores were higher than the positive reactivity scores.

To further examine the main effects and interaction effect of condition and parity status on the positive and negative reactivity scores a parity (two levels: parous, nulliparous) and emotion valence (two levels: positive reactivity, negative reactivity) repeated measures ANOVA was performed. There was a highly significant main effect of emotion valence $F(1,219) = 81.450$, $p < 2e\text{-}16$, $\eta^2_{partial} = 0.27$, and a significant main effect of parity $F(1,219) = 6.403$, $p < 0.0121$, $\eta^2_{partial} = 0.03$ on reactivity scores. There was not a significant interaction effect between parity and image type on reactivity scores $F(1,219) = 0.158$, $p = 0.691$, $\eta^2_{partial} < 0.01$.

Table 3

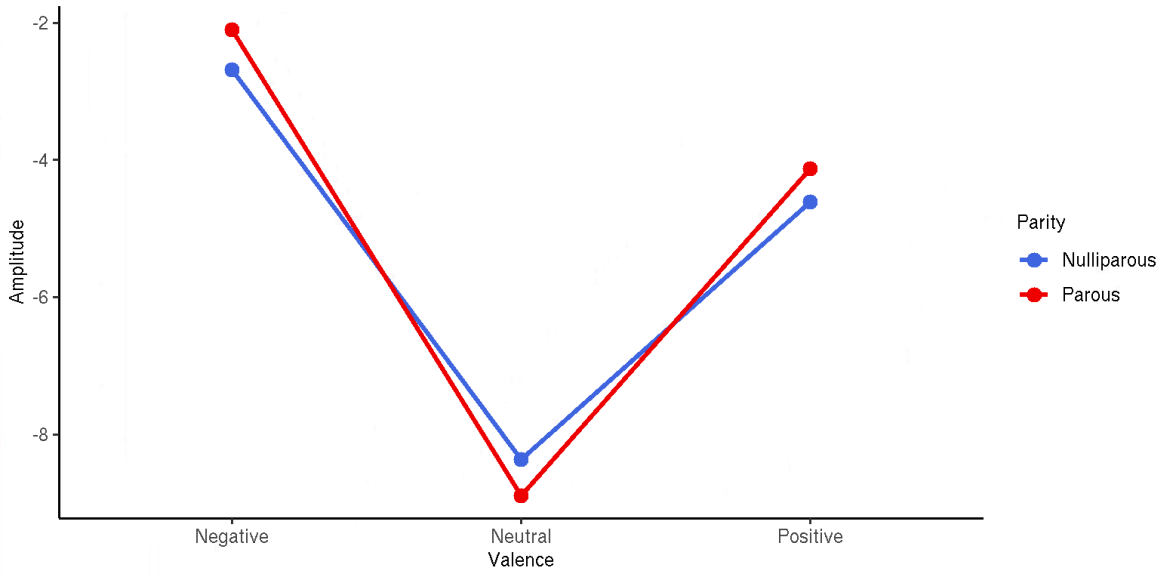
Means, standard deviations and t-tests for reactivity scores in both groups.

	Parous		Nulliparous		t-test			
	Mean	SD	Mean	SD	t-value	df	p-value	Cohens' d
Positive reactivity	4.75	2.62	3.83	3.16	-2.1824	219	0.030*	-0.31
Negative reactivity	6.71	3.19	5.62	3.56	-2.2752	219	0.024*	-0.32

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Figure 7

Interaction effects between parity status and average LPP amplitudes.

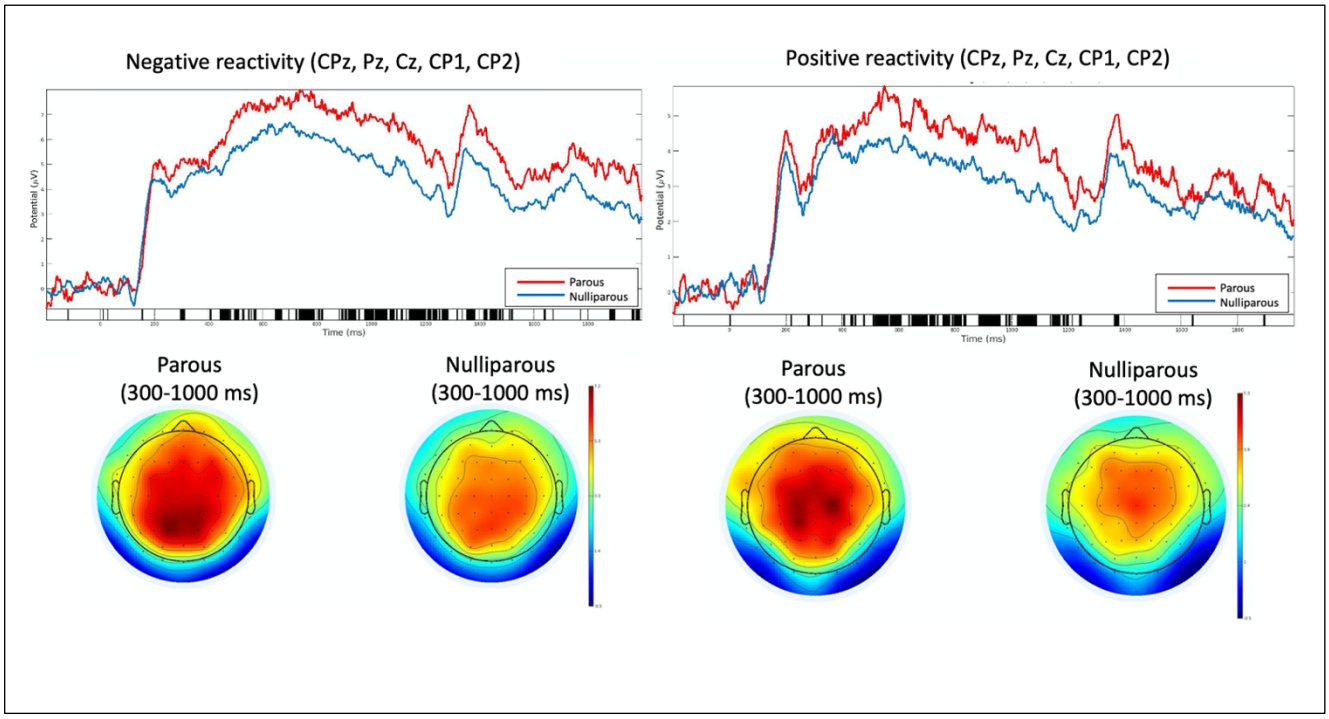


Two sensitivity analysis were performed for the 2x2 ANOVA for the reactivity scores, first excluding participants with history of other mental disorders than anxiety, depression, severe mental disorders, and second, excluding participants with less-than-ideal EEG data quality. For the sensitivity analysis for history of other mental disorders, 21 participants were excluded, resulting in a sample of 200 participants, with 69 participants in the parous group and 131 participants in the nulliparous group. The results were in line with

the main ANOVA for the reactivity scores, see Table 1 in the Appendix. In the second sensitivity analysis, two participants were excluded due to less-than-ideal EEG data quality, both were nulliparous. The total number of participants was 220, with 78 in the parous group and 142 in the nulliparous group. The results were consistent with the main ANOVA for the reactivity scores, see Table 1 in the Appendix.

Figure 8

Time course and scalp topography of negative and positive reactivity scores for the groups.



Follow-up analysis: Parity x emotion valence repeated measures ANCOVA for reactivity scores

After adjusting for age and PSQI global score, the follow up ANCOVA showed a highly significant main effect of condition $F(1,217) = 82.205$, $p < 2e\text{-}16$, $\eta^2_{partial} = 0.27$, and a main effect of parity $F(1,217) = 6.497$, $p = 0.0115$, $\eta^2_{partial} = 0.03$, and age $F(1,217) = 4.231$ $p = 0.0409$, $\eta^2_{partial} = 0.02$. There were no significant interaction effects between parity and emotion valence $F(1,217) = 0.159$, $p = 0.6900$, $\eta^2_{partial} < 0.001$, age and emotion valence $F(1,217) = 0.473$, $p = 0.4924$, $\eta^2_{partial} < 0.001$, and emotion valence and PSQI global score $F(1,217) = 3.557$, $p < 0.0606$, $\eta^2_{partial} = 0.02$.

After adjusting for the SEM for the LPP amplitudes, the 2x2 ANOCVA showed highly significant effect of emotion valence, $F(1,218)=81.930$, p <2e-16, $\eta^2_{partial} = 0.27$, parity $F(1,218)=6.603$, $p = 0.01084$, $\eta^2_{partial} = 0.03$, and SEM $F(1,218)=7.851$, $p = 0.00554$, $\eta^2_{partial} = 0.03$. The model did not detect significant interaction between emotion valence and parity $F(1,218)=0.159$, $p = 0.691$, $\eta^2_{partial} < 0.001$ or emotion valence and SEM $F(1,218)=2.290$, $p = 0.132$, , $\eta^2_{partial} = 0.01$.

H4: Reactivity scores and mental health

Multiple regression was used to explore relationships between questionnaire measures and LPP reactivity scores. First a multiple regression model with positive reactivity scores as response variable and age, parity, EPDS and GAD sum scores and PSQI global score as predictor variables. Age was the only significant predictor variable, and the overall model was significant, indicating that the model did provide fit for the data, see Table 4 for detailed results. Second, a multiple regression model was performed with negative reactivity as response variable and age, parity, EPDS, GAD sum scores and PSQI global score as predictor variable. Age was the only significant predictor variable, and the overall model was just above significance, see Table 5 for detailed results. Due to the assumption of multicollinearity the PSS sum score was not included in either model due to high correlations $r(0.97)$ with GAD sum score, see **Figure 1** in Appendix.

Table 4

Multiple regression for questionnaires and positive reactivity scores.

	B	Std. Error	t-value	p-value
Age	0.12106	0.06118	1.979	0.0491*
Parity	0.79531	0.45278	1.757	0.0804
EPDS sum score	-0.13687	0.07746	-1.767	0.787
GAD sum score	0.09093	0.09325	0.975	0.3306
PSQI global score	-0.15026	0.10258	-1.465	0.1444

Note. R-Squared value = 0.06247, $F(5,215)=2.938$, $p = 0.01583$*.*$p < 0.05$, **$p < 0.01$, ***$p< 0.001$

Table 5

Multiple regression for questionnaires and negative reactivity scores.

	B	Std. Error	t-value	p-value
Age	0.14616	0.07023	2.081	0.0386*
Parity	0.69476	0.51981	1.337	0.1828
EPDS sum score	-0.05063	0.08893	-0.569	0.5697
GAD sum score	-0.02098	0.10705	-0.196	0.8448
PSQI global score	0.04811	0.11776	0.409	0.6833

Note. R-Squared value = 0.04557, $F(5,215) = 2.273$, $p = 0.07255$. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Exploratory analysis: Reactivity scores and parity specific factors

Multiple regression analysis was performed to further investigate relationships between reactivity scores and factors specific to prior history of childbirth. First a regression model was performed on positive reactivity scores and its relationship with age, age at first childbirth and years since last childbirth. The model was not significant, and no predictor variables were significant, see Table 6. Secondly, a regression model was performed for the negative reactivity score and its relationship with age, age at first childbirth and years since last childbirth. The regression model was not significant, and no significant associations were found for age, age at first childbirth and years since last childbirth, see Table 7.

Table 6

Multiple regression for parity variables and positive reactivity.

	B	Std. Error	t-value	p-value
Intercept	1.25081	1.94000	0.645	0.5195
Age	-0.23012	0.38995	-0.590	0.557
Years since last childbirth	0.04868	0.46395	0.105	0.917
Age at first childbirth	0.37497	0.39410	0.951	0.344

Note. R-Squared value = 0.07738, $F(3,74) = 2.069$, $p = 0.1116$. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 7

Multiple regression for parity variables and negative reactivity.

	B	Std. Error	t-value	p-value
Intercept	1.09428	2.22718	0.491	0.6237
Age	0.4568	0.4718	0.968	0.3361
Years since last childbirth	-0.7652	0.5613	-1.363	0.1770
Age at first childbirth	-0.4174	0.4768	-0.875	0.3842

Note. R-Squared value = 0.03871, $F(3,74) = 0.9933$, $p = 0.4008$. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Discussion

The present study set out to investigate emotion processing in parous and nulliparous women by comparing average amplitudes and reactivity scores of the LPP in response to emotionally valenced and neutral stimuli. Several analyses were performed to investigate the relationship between LPP, parity, mental health, and factors specific to history of childbirth.

In support of the first hypothesis (H1), the results from the repeated measures ANOVA and follow-up comparisons, demonstrated more positive average LPP amplitudes in response to negatively and positively valenced images compared to neutral images. Moreover, the results showed more positive average LPP amplitudes in response to negatively valenced images compared to positively valenced images. This difference in the LPP amplitudes, were emotionally valenced compared to neutral stimuli elicit more positive amplitudes was consistent with previous literature on the LPP. The increased positivity in the LPP component in response to emotional stimuli has been proposed to reflect attentional allocation and reflection of the emotionally relevant stimuli (Cuthbert et al., 2000; Hajcak et al., 2010a). Therefore, the difference between the LPP amplitudes in all three conditions in the present study provided support for the experimental effect of the task paradigm.

The second hypothesis (H2) of the study, proposed an interaction between parity status and the effect of emotion valence on the LPP amplitudes. In support of the hypothesis the 2x3 repeated measures ANOVA detected an interaction effect between LPP and parity, and visualization of the effect revealed more positive amplitudes in response to the emotional

images and more negative amplitudes in response to neutral images in the parous group. The ANOVA did not detect a main effect of parity status, further highlighting how the difference between the group is only present when the interaction between emotion valence is considered. To further solidify these findings and rule out the possibility the results could be explained by difference in age and sleep quality between the groups, the follow-up ANCOVA models which adjusted for these group differences, replicated the interaction effect between parity and emotion valence. However, although the sensitivity analysis excluding participants with unspecified mental disorders was in line with the ANOVA, the interaction between parity and emotion valence reached the significance threshold, hence the interaction effect should be interpreted with caution.

Although differences between parous and nulliparous women in ERPs, when presented with emotionally valenced stimuli, have been reported (Noll et al., 2012; Peltola et al., 2014; Proverbio et al., 2006), one study has explicitly compared the LPP in parous and nulliparous women (Peltola et al., 2014). In contrast with the present study, Peltola and colleagues did not detect any interaction effect between parity status and average LPP amplitude in a repeated measures ANOVA. In their paper, an interaction effect of parity was detected on the EPN component and manifested as enhanced EPN response in parous women when presented with infants showing negatively valenced facial expressions. A possible explanation for the lack of interaction between parity and LPP and the interaction between parity and EPN could be that later occurring ERPs, such as the LPP, may not be affected by parity but rather earlier ERPs such as the EPN. However, considering that previous findings on the P300 demonstrated an interaction effect of parity, the authors of the paper did note that the discrepancy between the papers could have been due to differences in task paradigms (Peltola et al., 2014).

In addition to the interaction between parity and LPP amplitudes, differences in positive and negative reactivity scores were detected between the parous and nulliparous group using independent t-tests. Moreover, the main effect of parity was further supported by the 2x2 repeated measures ANOVA comparing the average reactivity scores between the groups and emotional valence (i.e., positive reactivity and negative reactivity). For both groups, the results showed larger negative reactivity scores compared to positive reactivity scores and both reactivity scores were larger in the parous group. Thus, the ANOVA provided support for the third hypothesis (H3), were differences between LPP amplitudes in response to emotional and neutral images was expected to be larger in the parous group. For

further support of the main effect of parity on the reactivity scores, the follow-up ANCOVAs, corrected for possible effects of group differences in age and sleep quality replicated the findings of the ANOVA. Together these findings suggest that the difference between the groups in the reactivity scores is most likely driving the interaction effect in the ANOVA for the LPP amplitudes.

The larger reactivity scores in the parous group suggest a stronger emotional response to images of emotional valence ompared to nulliparous women. Previous interpretations of the LPP suggest that the component reflects attentional allocation and sustained attention towards emotionally salient stimuli (Hajcak & Foti, 2020; Schindler & Bublatzky, 2020). Accordingly, the strong reactivity scores may reflect a more elaborative processing of emotional stimuli, especially negatively valence stimuli, in mothers compared to non-mothers. Therefore, the findings of the present study are in line with previous findings from the neuroimaging literature, suggesting a difference in emotion processing in parous and nulliparous women. In Proverbio et al. (2006), parous women compared to nulliparous women and fathers, showed a stronger P300 response when presented with infants depicting intense negative facial expressions. Therefore, the results of the current study are not only in line with Proverbio et al., but together, these results provide support for differences in emotion processing in parous and nulliparous at higher order processing stages beyond previously described differences at earlier processing states.

The potential effects of variables previously shown to affect LPP average amplitudes were further explored for both reactivity scores. The results from the regression models showed that overall, the models for both positive and negative reactivity scores were significant. In addition, the significance of the intercepts in both models suggested that the variance of the reactivity scores was explained by factors not included in the model. The only significant predictor variable detected with the reactivity scores in both regression models was age, demonstrating a positive relationship between age and the difference in the LPP between positive and neutral images. Therefore, the fourth hypothesis (H4), which stated a positive relationship between emotion reactivity and anxiety and depression symptoms and a negative relationship between sleep quality and emotion reactivity was not met. The lack of relationships detected between depression symptoms and the reactivity scores was in line with Nikolin et al., (2022). In their paper, exploratory analysis of various previously reported analysis pipelines could only reveal an effect of depression on LPP amplitudes in one analysis, suggesting the relationship between LPP and depression may not be as strong as

previously reported. Furthermore, the lack of relationship between anxiety and the reactivity scores was not consistent with previous findings suggesting a stronger response to emotionally valenced stimuli (MacNamara & Hajcak, 2010; Richards et al., 2013).

Lastly, relationships between factors specific to the parous group and the reactivity scores were explored. There were no relationships detected between the reactivity scores and the variables years since last childbirth and age at first childbirth. It is worth mentioning that 75.9% of the group gave birth within two and 40.5% within one year. Hence, a substantial portion of the sample was either currently or recently postpartum. Previous studies have shown differences in emotional response with years of parental experience (Gingell et al., 2015; Parsons et al., 2017). Moreover, considering reduced hormonal levels during the postpartum period, associated with breastfeeding, and a link between LPP and fluctuations in sex hormone levels, the skewness of the distribution of years since giving birth may have influenced the results.

Limitations and future directions

Limitations of the study are important to address and must be considered for the interpretation of the results. First, although the sample size was considerably larger than sample sizes in previous ERP studies researching parity, the group sizes were relatively uneven. As a result, the differences in group sizes may have affected the statistical comparisons and lead to reduced statistical power of the analysis. For more powered results, these comparisons should be repeated, preferably with larger and even sample sizes in the groups to further shed a light on the relationship between parity and the LPP.

Second, due to the cross-sectional design of the study, the results do not allow for causal inference between parity status and emotion reactivity. Despite adjusting for factors that differed between the groups, i.e., sleep and age, motherhood entails abundance of social and environmental demands that are not present or different from demands in life for nulliparous women. Hence, there are likely additional systematic differences between the groups that were not accounted for in the present study. For example, the present study did not account for perceived social support, which has been shown to modulate LPP amplitudes in women postpartum (Nyman et al., 2020). In addition to environmental and social differences, differences in menstrual cycle phase and estradiol levels in parous and nulliparous women may also interact with the relationship between LPP and parity. LPP amplitudes in response to emotional and arousing stimuli have been shown to be specifically

related to estradiol levels as well as use of hormonal contraception and menstrual cycle phase (Monciunskaite et al., 2019; Munk et al., 2020). In parous women, menstrual cycles have been shown to be shorter and estradiol levels lower (Barrett et al., 2014; Dorgan et al., 1995), therefore, hormonal differences between the groups were a possible confounding factor. Additionally, given the short time since many of the participants gave birth, some women may have been breastfeeding, leading to differences in hormonal levels within the parous group (Hendrick et al., 1998). Therefore, a longitudinal design adjusting for hormone levels, based on within-individual comparisons of the LPP before and after giving birth for the first time, would better target the development of the LPP during the transitioning into motherhood.

Finally, the results must be interpreted considering the homogeneity of the sample. Both groups were similar regarding demographic factors, history of anxiety and depression and measures of perceived stress, anxiety, and depressive symptoms. Furthermore, average scores on the GAD and EPDS scales were below recommended clinical cut of scores for both groups. Thus, the results indicate a healthy sample in respect to mental health. A sampling bias in the study may explain the homogeneity of mental health variables within the sample. For example, in view of the data collection taking place during the COVID-19 pandemic, one study showed that in a sample of approximately 5000 pregnant or postpartum women, around 17% experienced severe depression and anxiety symptoms (Tauqeer et al., 2023). Hence, the sample may not accurately represent the population. Although the similarities between the group allow for more control for the comparisons of the LPP, the results of the present study potentially lack external validity. Therefore, further research is required to explore the relationship between LPP and parity in diverse samples women for more generalizability.

Conclusion

In conclusion, the results from the present study provide evidence for small but significant differences in emotion processing between parous and nulliparous women, reflected by stronger reactivity in LPP amplitudes in parous compared to nulliparous women. The study provides support to previous neuroimaging studies demonstrating differences in neural activity in response to emotionally valenced stimuli in parous and nulliparous women. For a more comprehensive understanding of the effects of parity on the LPP, further research is needed, utilizing both average amplitudes and reactivity scores, in well-powered and more diverse samples to gain a clear understanding of the effect of parity on emotion processing.

References

Aleknaviciute, J., Evans, T. E., Aribas, E., de Vries, M. W., Steegers, E. A. P., Ikram, M. A., Tiemeier, H., Kavousi, M., Vernooij, M. W., & Kushner, S. A. (2022). Long-term association of pregnancy and maternal brain structure: The Rotterdam Study. *European Journal of Epidemiology*, *37*(3), 271–281. https://doi.org/10.1007/s10654-021-00818-5

Alfarra, R., Fins, A. I., Chayo, I., & Tartar, J. L. (2015). Changes in attention to an emotional task after sleep deprivation: Neurophysiological and behavioral findings. *Biological Psychology*, *104*, 1–7. https://doi.org/10.1016/j.biopsycho.2014.11.001

Álvarez, F., Fernández-Folgueiras, U., Méndez-Bértolo, C., Kessel, D., & Carretié, L. (2022). Menstrual cycle and exogenous attention toward emotional expressions. *Hormones and Behavior*, *146*, 1-9. https://doi.org/10.1016/j.yhbeh.2022.105259

American Psychological Association. (n.d.). Emotion regulation. In *APA dictionary of psychology*. Retrieved April, 25, 2023, from https://dictionary.apa.org/emotion-regulation

Amin, Z., Epperson, C. N., Constable, R. T., & Canli, T. (2006). Effects of estrogen variation on neural correlates of emotional response inhibition. *NeuroImage*, *32*(1), 457–464. https://doi.org/10.1016/j.neuroimage.2006.03.013

Cohen, S. (1988). Perceived stress in a probability sample of the United States. In *The social psychology of health* (pp. 31–67). Sage Publications, Inc.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Academic press.

Barrett, E. S., Parlett, L. E., Windham, G. C., & Swan, S. H. (2014). Differences in ovarian hormones in relation to parity and time since last birth. *Fertility and Sterility*, *101*(6), 1773-1780.e1. https://doi.org/10.1016/j.fertnstert.2014.02.047

Barth, C., Villringer, A., & Sacher, J. (2015). Sex hormones affect neurotransmitters and shape the adult female brain during hormonal transition periods. *Frontiers in Neuroscience*, *9*, 37, 1-20. https://doi.org/10.3389/fnins.2015.00037

Ben-Shachar MS, Lüdecke D, Makowski D (2020). "effectsize: Estimation of Effect Size Indices and Standardized Parameters." *Journal of Open Source Software*, **5**(56), 2815. doi:10.21105/joss.02815

Bigdely-Shamlo, N., Mullen, T., Kothe, C., Su, K.-M., & Robbins, K. A. (2015). The PREP pipeline: Standardized preprocessing for large-scale EEG analysis. *Frontiers in Neuroinformatics*, *9*(16), 1-20. https://doi.org/10.3389/fninf.2015.00016

Burkhouse, K. L., Woody, M. L., Owens, M., & Gibb, B. E. (2015). Influence of worry on sustained attention to emotional stimuli: Evidence from the late positive potential. *Neuroscience Letters*, *588*, 57–61. https://doi.org/10.1016/j.neulet.2014.11.006

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Carmona, S., Martínez-García, M., Paternina-Die, M., Barba-Müller, E., Wierenga, L. M., Alemán-Gómez, Y., … Hoekzema, E. (2019). Pregnancy and adolescence entail similar neuroanatomical adaptations: A comparative analysis of cerebral morphometric changes. *Human Brain Mapping*, *40*(7), 2143–2152. https://doi.org/10.1002/hbm.24513

Carpenter, J. S., & Andrykowski, M. A. (1998). Psychometric evaluation of the Pittsburgh Sleep Quality Index. *Journal of Psychosomatic Research*, *45*(1), 5–13. https://doi.org/10.1016/s0022-3999(97)00298-5

Carretié, L., Tapia, M., López-Martín, S., & Albert, J. (2019). EmoMadrid: An emotional pictures database for affect research. *Motivation and Emotion, 43,* 929-939.

Citron, F. M. M. (2012). Neural correlates of written emotion word processing: A review of recent electrophysiological and hemodynamic neuroimaging studies. *Brain and Language*, *122*(3), 211–226. https://doi.org/10.1016/j.bandl.2011.12.007

Cole, J. H., Ritchie, S. J., Bastin, M. E., Valdés Hernández, M. C., Muñoz Maniega, S., Royle, N., Corley, J., Pattie, A., Harris, S. E., Zhang, Q., Wray, N. R., Redmond, P., Marioni, R. E., Starr, J. M., Cox, S. R., Wardlaw, J. M., Sharp, D. J., & Deary, I. J. (2018). Brain age predicts mortality. *Molecular Psychiatry*, *23*(5), 1385-1392. https://doi.org/10.1038/mp.2017.62

Coll, M. P. (2018). Meta-analysis of ERP investigations of pain empathy underlines methodological issues in ERP research. *Social Cognitive and Affective Neuroscience*, *13*(10), 1003–1017. https://doi.org/10.1093/scan/nsy072

Cote, K., Jancsar, C., & Hunt, B. (2015). Event-related neural response to emotional picture stimuli following sleep deprivation. *Psychology & Neuroscience*, *8*, 102–113. https://doi.org/10.1037/h0100354

Cox, J. L., Chapman, G., Murray, D., & Jones, P. (1996). Validation of the Edinburgh Postnatal Depression Scale (EPDS) in non-postnatal women. *Journal of Affective Disorders*, *39*(3), 185–189. https://doi.org/10.1016/0165-0327(96)00008-0

Cox, J. L., Holden, J. M., & Sagovsky, R. (1987). Detection of postnatal depression. Development of the 10-item Edinburgh Postnatal Depression Scale. *The British Journal of Psychiatry: The Journal of Mental Science*, *150*, 782–786. https://doi.org/10.1192/bjp.150.6.782

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. *Biological Psychology*, *52*(2), 95–111. https://doi.org/10.1016/S0301-0511(99)00044-7

Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva affective picture database (GAPED): a new 730-picture database focusing on valence and normative significance. Behavior Research Methods, 43(2), 468.

de Lange, A.-M. G., Kaufmann, T., van der Meer, D., Maglanoc, L. A., Alnæs, D., Moberget, T., Douaud, G., Andreassen, O. A., & Westlye, L. T. (2019). Population-based neuroimaging reveals traces of childbirth in the maternal brain. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(44), 22341–22346. https://doi.org/10.1073/pnas.1910666116

de Lange, A.-M. G., Barth, C., Kaufmann, T., Anatürk, M., Suri, S., Ebmeier, K. P., & Westlye, L. T. (2020). The maternal brain: Region-specific patterns of brain aging are traceable decades after childbirth. *Human Brain Mapping*, *41*(16), 4718–4729. https://doi.org/10.1002/hbm.25152

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Dorgan, J. F., Reichman, M. E., Judd, J. T., Brown, C., Longcope, C., Schatzkin, A., Campbell, W. S., Franz, C., Kahle, L., & Taylor, P. R. (1995). Relationships of age and reproductive characteristics with plasma estrogens and androgens in premenopausal women. *Cancer Epidemiology, Biomarkers & Prevention*, *4*(4), 381–386.

Dunning, J. P., & Hajcak, G. (2009). See no evil: Directing visual attention within unpleasant images modulates the electrocortical response. *Psychophysiology*, *46*(1), 28–33. https://doi.org/10.1111/j.1469-8986.2008.00723.x

Eberhard-Gran, M., Eskild, A., Tambs, K., Opjordsmoen, S., & Samuelsen, S. O. (2001). Review of validation studies of the Edinburgh Postnatal Depression Scale. *Acta*

Psychiatrica Scandinavica, *104*(4), 243–249. https://doi.org/10.1034/j.1600-0447.2001.00187.x

Elliott, M. L., Belsky, D. W., Knodt, A. R., Ireland, D., Melzer, T. R., Poulton, R., Ramrakha, S., Caspi, A., Moffitt, T. E., & Hariri, A. R. (2021). Brain-age in midlife is associated with accelerated biological aging and cognitive decline in a longitudinal birth cohort. *Molecular Psychiatry*, *26*(8), Article 8. https://doi.org/10.1038/s41380-019-0626-7

Fleischman, D. S., Navarrete, C. D., & Fessler, D. M. T. (2010). Oral Contraceptives Suppress Ovarian Hormone Production. *Psychological Science*, *21*(5), 750–752.

Foti, D., Olvet, D. M., Klein, D. N., & Hajcak, G. (2010). Reduced electrocortical response to threatening faces in major depressive disorder. *Depression and Anxiety*, *27*(9), 813–820. https://doi.org/10.1002/da.20712

Gao, C., Wedell, D. H., Green, J. J., Jia, X., Mao, X., Guo, C., & Shinkareva, S. V. (2018). Temporal dynamics of audiovisual affective processing. *Biological Psychology*, *139*, 59–72. https://doi.org/10.1016/j.biopsycho.2018.10.001

Gingnell, M., Bannbers, E., Moes, H., Engman, J., Sylvén, S., Skalkidou, A., Kask, K., Wikström, J., & Sundström-Poromaa, I. (2015). Emotion reactivity is increased 4-6 weeks postpartum in healthy women: A longitudinal fMRI study. *PLoS One*, *10*(6), e0128964. https://doi.org/10.1371/journal.pone.0128964

Goldstein, J. M., Jerram, M., Poldrack, R., Ahern, T., Kennedy, D. N., Seidman, L. J., & Makris, N. (2005). Hormonal cycle modulates arousal circuitry in women using functional magnetic resonance imaging. *Journal of Neuroscience*, *25*(40), 9309–9316. https://doi.org/10.1523/JNEUROSCI.2239-05.2005

Gootjes, L., Coppens, L. C., Zwaan, R. A., Franken, I. H. A., & Van Strien, J. W. (2011). Effects of recent word exposure on emotion-word Stroop interference: An ERP study. *International Journal of Psychophysiology*, *79*(3), 356–363. https://doi.org/10.1016/j.ijpsycho.2010.12.003

Grolleman, J. F., Gravesteijn, C., & Hoffenaar, P. J. (2023). Trajectories of change in parental self-esteem and emotion regulation from pregnancy until 4 years postpartum. *Journal of Child and Family Studies*, *32*(4), 1088–1101. https://doi.org/10.1007/s10826-022-02306-0

Hafkemeijer, A., Altmann-Schneider, I., de Craen, A. J. M., Slagboom, p. E., van der Grond, J., & Rombouts, S. A. R. B. (2014). Associations between age and gray matter

volume in anatomical brain networks in middle-aged to older adults. *Aging Cell*, *13*(6), 1068-1074. https://onlinelibrary.wiley.com/doi/full/10.1111/acel.12271

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology*, *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), e13570. https://doi.org/10.1111/psyp.13570

Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-related potentials, emotion, and emotion regulation: An integrative review. *Developmental Neuropsychology*, *35*(2), 129–155. https://doi.org/10.1080/87565640903526504

Hendrick, V., Altshuler, L. L., & Suri, R. (1998). Hormonal Changes in the Postpartum and Implications for Postpartum Depression. *Psychosomatics*, *39*(2), 93–101. https://doi.org/10.1016/S0033-3182(98) 71355-6

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. *Nature Neuroscience*, *20*(2), 287–296. https://doi.org/10.1038/nn.4458

Hoekzema, E., van Steenbergen, H., Straathof, M., Beekmans, A., Freund, I. M., Pouwels, P. J. W., & Crone, E. A. (2022). Mapping the effects of pregnancy on resting state brain activity, white matter microstructure, neural metabolite concentrations and grey matter architecture. *Nature Communications*, *13*(1), 6931. https://doi.org/10.1038/s41467-022-33884-8

Holinger, D. P., Hill, S. A., Martin, D. L., Faux, S. F., Ives, J. R., & Schomer, D. L. (2000). Reappraisal of filter effects on P300 voltage and latency. *Journal of Clinical Neurophysiology*, *17*(3), 331-335. https://doi.org/10.1097/00004691-200005000-00011

Huffmeijer, R., Alink, L. R. A., Tops, M., Grewen, K. M., Light, K. C., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2013). The impact of oxytocin administration and maternal love withdrawal on event-related potential (ERP) responses to emotional faces with performance feedback. *Hormones and Behavior*, *63*(3), 399–410. https://doi.org/10.1016/j.yhbeh.2012.11.008

Huynh, H., & Feldt, L. S. (1976). Estimation of the Box correction for degrees of freedom from sample data in randomized block and split-plot designs. *Journal of Educational Statistics*, *1*, 69–82. https://doi.org/10.2307/1164736

İnce, S. & Albar, N.Y.(2022). Physiological changes during the postpartum Period: General overview. In Cingi, C., Özel, H. E., & Muluk., N. B., ENT Diseases: Diagnosis and Treatment during Pregnancy and Lactation (pp.29). Springer. https://doi.org/10.1007/978-3-031-05303-0

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

Klawohn, J., Burani, K., Bruchnak, A., Santopetro, N., & Hajcak, G. (2021). Reduced neural response to reward and pleasant pictures independently relate to depression. *Psychological Medicine*, *51*(5), 741–749. https://doi.org/10.1017/S0033291719003659

Kurdi, B., Lozano, S., & Banaji, M. R. (2017). Introducing the Open Affective Standardized Image Set (OASIS). Behavior Research Methods, *49*(2), 457–470. http://doi.org/10.3758/s13428-016-0715-3

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. *Developmental Psychology*, *56*(6), 1170–1190. https://doi.org/10.1037/dev0000928

Levine, A., Zagoory-Sharon, O., Feldman, R., & Weller, A. (2007). Oxytocin during pregnancy and early postpartum: Individual patterns and maternal-fetal attachment. *Peptides*, *28*(6), 1162–1169. https://doi.org/10.1016/j.peptides.2007.04.016

Liu, Y., Huang, H., McGinnis-Deweese, M., Keil, A., & Ding, M. (2012). Neural Substrate of the Late Positive Potential in Emotional Processing. *The Journal of Neuroscience*, *32*(42), 14563–14572. https://doi.org/10.1523/JNEUROSCI.3109-12.2012

Luck, S. J. (2014). *An Introduction to the Event-Related Potential Technique* (2nd ed.). MIT Press.

Luck, S. J., Stewart, A. X., Simmons, A. M., & Rhemtulla, M. (2021). Standardized measurement error: A universal metric of data quality for averaged event-related potentials. *Psychophysiology*, *58*(6), e13793. https://doi.org/10.1111/psyp.13793

Lusk, B. R., Carr, A. R., Ranson, V. A., Bryant, R. A., & Felmingham, K. L. (2015). Early visual processing is enhanced in the midluteal phase of the menstrual cycle.

Psychoneuroendocrinology, *62*, 343–351. https://doi.org/10.1016/j.psyneuen.2015.08.022

Lusk, B. R., Carr, A. R., Ranson, V. A., & Felmingham, K. L. (2017). Women in the midluteal phase of the menstrual cycle have difficulty suppressing the processing of negative emotional stimuli: An event-related potential study. *Cognitive, Affective & Behavioral Neuroscience*, *17*(4), 886–903. https://doi.org/10.3758/s13415-017-0520-1

Lustig, K. A., Stoakley, E. M., MacDonald, K. J., Geniole, S. N., McCormick, C. M., & Cote, K. A. (2018). Sex hormones play a role in vulnerability to sleep loss on emotion processing tasks. *Neurobiology of Sleep and Circadian Rhythms*, *5*, 94–104. https://doi.org/10.1016/j.nbscr.2017.10.001

MacNamara, A., Foti, D., & Hajcak, G. (2009). Tell me about it: Neural activity elicited by emotional pictures and preceding descriptions. *Emotion*, *9*, 531–543. https://doi.org/10.1037/a0016251

MacNamara, A., & Hajcak, G. (2010). Distinct electrocortical and behavioral evidence for increased attention to threat in generalized anxiety disorder. *Depression and Anxiety*, *27*(3), 234–243. https://doi.org/10.1002/da.20679

MacNamara, A., & Proudfit, G. H. (2014). Cognitive load and emotional processing in generalized anxiety disorder: Electrocortical evidence for increased distractibility. *Journal of Abnormal Psychology*, *123*(3), 557–565. https://doi.org/10.1037/a0036997

Marchewka, A., Żurawski, Ł., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. Behavior Research Methods, *46*(2), 596-610. https://doi.org/10.3758/s13428-013-0379-1

MathWorks. (2021). MATLAB R2021b: Natick, MA: MathWorks.

Mauchly, J. W. (1940). Significance test for sphericity of a normal n-variate distribution. *The Annals of Mathematical Statistics*, *11*(2), 204–209. http://www.jstor.org/stable/2235878

Maupin, A. N., Rutherford, H. J. V., Landi, N., Potenza, M. N., & Mayes, L. C. (2019). Investigating the association between parity and the maternal neural response to infant cues. *Social Neuroscience*, *14*(2), 214–225. https://doi.org/10.1080/17470919.2017.1422276

Mollayeva, T., Thurairajah, P., Burton, K., Mollayeva, S., Shapiro, C. M., & Colantonio, A. (2016). The Pittsburgh sleep quality index as a screening tool for sleep dysfunction in

clinical and non-clinical samples: A systematic review and meta-analysis. *Sleep Medicine Reviews*, *25*, 52–73. https://doi.org/10.1016/j.smrv.2015.01.009

Monciunskaite, R., Malden, L., Lukstaite, I., Ruksenas, O., & Griksiene, R. (2019). Do oral contraceptives modulate an ERP response to affective pictures? *Biological Psychology*, *148*, 107767. https://doi.org/10.1016/j.biopsycho.2019.107767

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

Moses-Kolko, E. L., Banihashemi, L., & Hipwell, A. E. (2021). Reduced postpartum hippocampal volume is associated with positive mother-infant caregiving behavior. *Journal of Affective Disorders*, *281*, 297–302. https://doi.org/10.1016/j.jad.2020.12.014

Mulligan, E. M., Simon, J., Lowe, M., Santopetro, N., Flynn, H., & Hajcak, G. (2022). The P300 and late positive potential in pregnancy prospectively predict increases in depressive and anxious symptoms in the early postpartum period. *Journal of Affective Disorders*, *317*, 193–203. https://doi.org/10.1016/j.jad.2022.08.035

Munk, A. J. L., Dickhaeuser, L., Breitinger, E., Hermann, A., Strahler, J., Schmidt, N. M., & Hennig, J. (2020). Females' menstrual cycle and incentive salience: Insights on neural reaction towards erotic pictures and effects of gonadal hormones. *Comprehensive Psychoneuroendocrinology*, *3*, 100006. https://doi.org/10.1016/j.cpnec.2020.100006

Munk, A. J. L., Zoeller, A. C., & Hennig, J. (2018). Fluctuations of estradiol during women's menstrual cycle: Influences on reactivity towards erotic stimuli in the late positive potential. *Psychoneuroendocrinology*, *91*, 11–19. https://doi.org/10.1016/j.psyneuen.2018.02.028

Nikolin, S., Chand, N., Martin, D., Rushby, J., Loo, C. K., & Boonstra, T. W. (2022). Little evidence for a reduced late positive potential to unpleasant stimuli in major depressive disorder. *Neuroimage: Reports*, *2*(1), 100077. https://doi.org/10.1016/j.ynirp.2022.100077

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. *Social Neuroscience*, *7*(5), 525–536. https://doi.org/10.1080/17470919.2012.672457

Nunez, P. L., Silberstein, R. B., Cadusch, P. J., Wijesinghe, R. S., Westdorp, A. F., & Srinivasan, R. (1994). A theoretical and experimental study of high resolution EEG

based on surface laplacians and cortical imaging. *Electroencephalography and Clinical Neurophysiology*, *90*(1), 40–57. https://doi.org/10.1016/0013-4694(94)90112-0

Nyman, T., Pegg, S., Kiel, E. J., Mistry-Patel, S., Becker-Schmall, L. J., & Brooker, R. J. (2020). Perceived Social Support Moderates Neural Reactivity to Emotionally-Valenced Stimuli During Pregnancy. *Psychophysiology*, *57*(11), e13647. https://doi.org/10.1111/psyp.13647

Oatridge, A., Holdcroft, A., Saeed, N., Hajnal, J. V., Puri, B. K., Fusi, L., & Bydder, G. M. (2002). Change in brain size during and after pregnancy: Study in healthy women and women with preeclampsia. *American Journal of Neuroradiology*, *23*(1), 19–26.

Osborne, J., & Waters, E. (2019). Four assumptions of multiple regression that researchers should always test. *Practical Assessment, Research, and Evaluation*, *8*(1), 1-5. https://doi.org/10.7275/r222-hv23

Parsons, C. E., Young, K. S., Petersen, M. V., Jegindoe Elmholdt, E.-M., Vuust, P., Stein, A., & Kringelbach, M. L. (2017). Duration of motherhood has incremental effects on mothers' neural processing of infant vocal cues: A neuroimaging study of women. *Scientific Reports*, *7*(1), 1727. https://doi.org/10.1038/s41598-017-01776-3

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

Peterson, N. N., Schroeder, C. E., & Arezzo, J. C. (1995). Neural generators of early cortical somatosensory evoked potentials in the awake monkey. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *96*(3), 248–260. https://doi.org/10.1016/0168-5597(95)00006-E

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, *37*(2), 127–152.

Pion-Tonachini, L., Kreutz-Delgado, K., & Makeig, S. (2019). ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. *NeuroImage*, *198*, 181–197. https://doi.org/10.1016/j.neuroimage.2019.05.026

Plank, I., Hindi Attar, C., Kunas, S., Dziobek, I., & Bermpohl, F. (2021). Motherhood and empathy: Increased activation in empathy areas in response to other's in pain. *Sci Rep,* 11, 22757. https://doi.org/10.21203/rs.3.rs-478801/v1

Plummer, F., Manea, L., Trepel, D., & McMillan, D. (2016). Screening for anxiety disorders with the GAD-7 and GAD-2: A systematic review and diagnostic metaanalysis. *General Hospital Psychiatry*, *39*, 24–31.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Protopopescu, X., Pan, H., Altemus, M., Tuescher, O., Polanecsky, M., McEwen, B., Silbersweig, D., & Stern, E. (2005). Orbitofrontal cortex activity related to emotional processing changes across the menstrual cycle. *Proceedings of the National Academy of Sciences*, *102*(44), 16060–16065. https://doi.org/10.1073/pnas.0502818102

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

Purhonen, M., Valkonen-Korhonen, M., & Lehtonen, J. (2008). The impact of stimulus type and early motherhood on attentional processing. *Developmental Psychobiology*, *50*(6), 600–607. https://doi.org/10.1002/dev.20321

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rehbein, E., Hornung, J., Sundström Poromaa, I., & Derntl, B. (2021). Shaping of the female human brain by sex hormones: A Review. *Neuroendocrinology*, *111*(3), 183–206. https://doi.org/10.1159/000507083

Richards, A., Holmes, A., Pell, P. J., & Bethell, E. J. (2013). Adapting effects of emotional expression in anxiety: Evidence for an enhanced Late Positive Potential. *Social Neuroscience*, *8*(6), 650–664. https://doi.org/10.1080/17470919.2013.854273

Rodrigo, M. J., León, I., Quiñones, 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. *Development and Psychopathology*, *23*(1), 163–176. https://doi.org/10.1017/S0954579410000714

Rubertsson, C., Börjesson, K., Berglund, A., Josefsson, A., & Sydsjö, G. (2011). The Swedish validation of Edinburgh Postnatal Depression Scale (EPDS) during

pregnancy. *Nordic Journal of Psychiatry*, *65*(6), 414–418. https://doi.org/10.3109/08039488.2011.590606

Russell, J. A., Douglas, A. J., & Ingram, C. D. (2001). Brain preparations for maternity: Adaptive changes in behavioral and neuroendocrine systems during pregnancy and lactation. An overview. *Progress in Brain Research*, *133*, 1–38. https://doi.org/10.1016/s0079-6123(01)33002-9

Rutherford, H. J. V., Crowley, M. J., Gao, L., Francis, B., Schultheis, A., & Mayes, L. C. (2018). Prenatal neural responses to infant faces predict postpartum reflective functioning. *Infant Behavior and Development*, *53*, 43–48. https://doi.org/10.1016/j.infbeh.2018.09.003

Rutherford, H. J. V., Wallace, N. S., Laurent, H. K., & Mayes, L. C. (2015). Emotion regulation in parenthood. *Developmental Review*, *36*, 1–14. https://doi.org/10.1016/j.dr.2014.12.008

RStudio Team (2021). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/

Sabatinelli, D., Lang, P. J., Keil, A., & Bradley, M. M. (2006). Emotional perception: Correlation of functional MRI and event-related potentials. *Cerebral Cortex*, *17*(5), 1085–1091. https://doi.org/10.1093/cercor/bhl017

Schindler, S., & Bublatzky, F. (2020). Attention and emotion: An integrative review of emotional face processing as a function of attention. *Cortex*, *130*, 362–386. https://doi.org/10.1016/j.cortex.2020.06.010

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2003). Attention and emotion: An ERP analysis of facilitated emotional stimulus processing. *Neuroreport*, *14*(8), 1107–1110. https://doi.org/10.1097/00001756-200306110-00002

Sokhadze, E. M., Casanova, M. F., Casanova, E. L., Lamina, E., Kelly, D. P., & Khachidze, I. (2017). Event-related potentials (ERP) in cognitive neuroscience research and applications. *NeuroRegulation*, *4*(1), 14-27. https://doi.org/10.15540/nr.4.1.14

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: The GAD-7. *Archives of Internal Medicine*, *166*(10), 1092–1097. https://doi.org/10.1001/archinte.166.10.1092

Tauqeer, F., Ceulemans, M., Gerbier, E., Passier, A., Oliver, A., Foulon, V., Panchaud, A., Lupattelli, A., & Nordeng, H. (2023). Mental health of pregnant and postpartum women during the third wave of the COVID-19 pandemic: A European cross-

sectional study. *BMJ Open*, *13*(1), e063391. https://doi.org/10.1136/bmjopen-2022-063391

Voldsbekk, I., Barth, C., Maximov, I. I., Kaufmann, T., Beck, D., Richard, G., Moberget, T., Westlye, L. T., & de Lange, A.-M. G. (2021). A history of previous childbirths is linked to women's white matter brain age in midlife and older age. *Human Brain Mapping*, *42*(13), 4372–4386. https://doi.org/10.1002/hbm.25553

Voss, P., Thomas, M. E., Cisneros-Franco, J. M., & Villers-Sidani, É. de. (2017). Dynamic brains and the changing rules of neuroplasticity: Implications for learning and recovery. *Frontiers in Psychology*, *8*, 1675. https://doi.org/10.3389/fpsyg.2017.01657

Vuoriainen, E., Bakermans-Kranenburg, M. J., Huffmeijer, R., van IJzendoorn, M. H., & Peltola, M. J. (2022). Processing children's faces in the parental brain: A meta-analysis of ERP studies. *Neuroscience & Biobehavioral Reviews*, *136*, 104604. https://doi.org/10.1016/j.neubiorev.2022.104604

Weidner, E. M., Schindler, S., Grewe, P., Moratti, S., Bien, C. G., & Kissler, J. (2022). Emotion and attention in face processing: Complementary evidence from surface event-related potentials and intracranial amygdala recordings. *Biological Psychology*, *173*, 108399. https://doi.org/10.1016/j.biopsycho.2022.108399

Weinberg, A., & Hajcak, G. (2011). The late positive potential predicts subsequent interference with target processing. *Journal of Cognitive Neuroscience*, *23*(10), 2994–3007. https://doi.org/10.1162/jocn.2011.21630

Weinberg, A., Perlman, G., Kotov, R., & Hajcak, G. (2016). Depression and reduced neural response to emotional images: Distinction from anxiety, and importance of symptom dimensions and age of onset. *Journal of Abnormal Psychology*, *125*(1), 26–39. https://doi.org/10.1037/abn0000118

Weinberg, A., & Sandre, A. (2018). Distinct Associations Between Low Positive Affect, Panic, and Neural Responses to Reward and Threat During Late Stages of Affective Picture Processing. *Biological Psychiatry. Cognitive Neuroscience and Neuroimaging*, *3*(1), 59–68. https://doi.org/10.1016/j.bpsc.2017.09.013

Wessa, M., Kanske, P., Neumeister, P., Bode, K., Heissler, J., & Schönfelder, S. (2010). EmoPics: Subjektive und psychophysiologische Evaluation neuen Bildmaterials für die klinisch-biopsychologische Forschung. *Zeitschrift Für Klinische Psychologie Und Psychotherapie*, *39*.

Zhang, W., Zhou, R., Wang, Q., Zhao, Y., & Liu, Y. (2013). Sensitivity of the late positive potentials evoked by emotional pictures to neuroticism during the menstrual cycle. *Neuroscience Letters*, *553*, 7–12. https://doi.org/10.1016/j.neulet.2013.06.037

Appendix

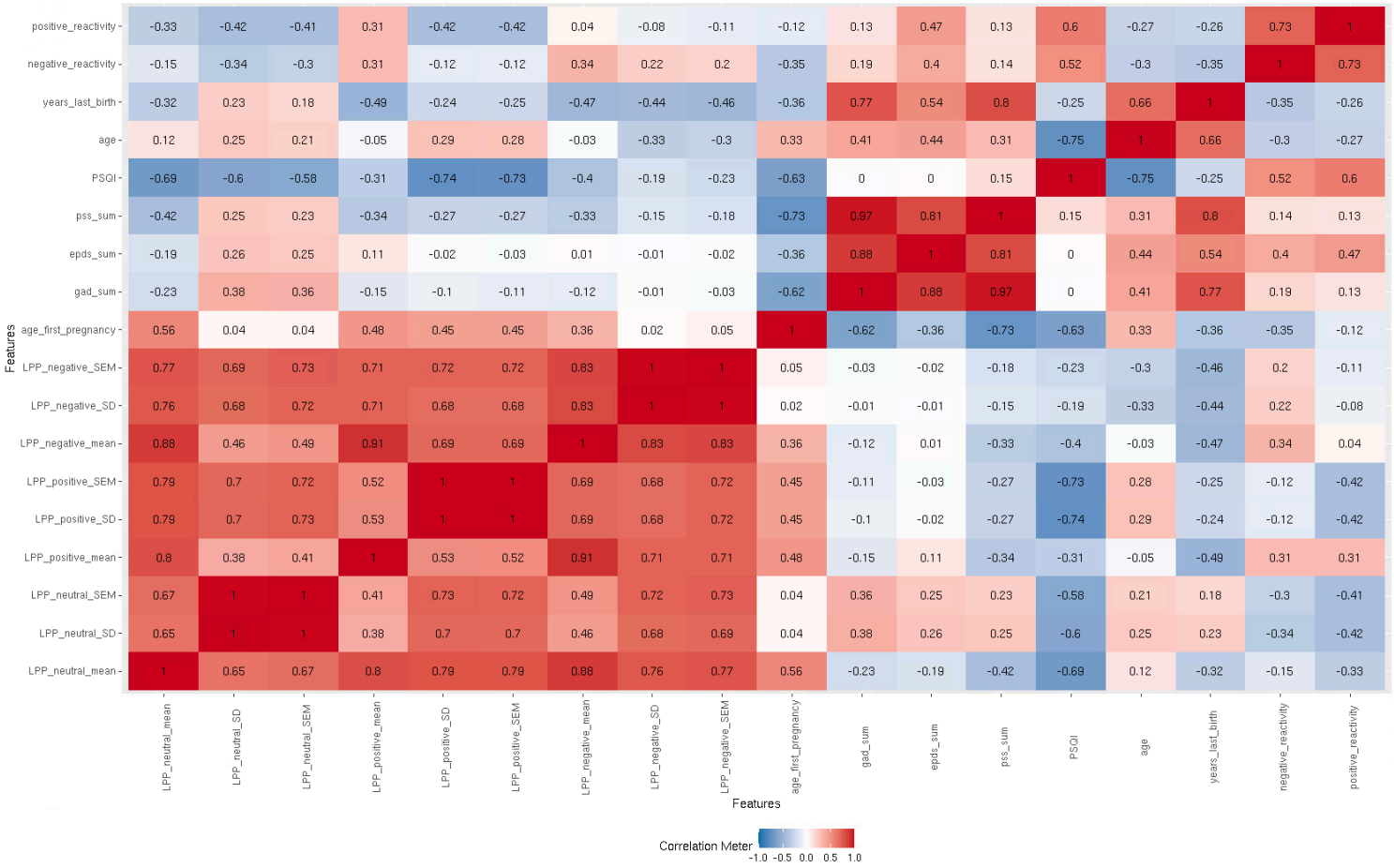
Supplementary table 1

Pictures and photo corpora included in the compturized task.

EmoPics	"21", "63", "61", "173", "146", "148", "199", "145", "126", "106", "121", "119", "114", "172", "180", "109", "165", "93", "133", "143", "105", "129", "128", "188", "201", "144", "161", "125", "127", "208", "211", "213", "214", "215", "220", "223", "224", "225", "227", "228", "231", "232", "233", "234", "240", "243", "251", "252"
EmoMadrid	"EM0417", "EM0368", "EM0709", "EM0359", "EM0461", "EM0718", "EM0435", "EM0360", "EM0454", "EM0665", "EM0635", "EM0363", "EM0710", "EM0719", "EM0730", "EM0376"
OASIS	"Siblings 1", "Baby 8", "Mother 6", "Mother 4", "Mother 7", "Father 1", "Mother 8", "Baby 3", "School 2", "Couple 8", "Couple 6", "Parachuting 3", "Neutral face 1", "Sad face 1", "Miserable face 2"
NAPS	"Faces_001_h", "Faces_340_h", "Faces_107_h", "People_180_h", "Faces_134_h", "Faces_089_h", "Faces_182_h", "Faces_172_h"
GAPED	"H034.jpg", "H099.jpg", "H100.jpg"

Supplementary figure

Correlation matrix with all variables included in the thesis.



Supplementary table 2

Results from sensitivity analysis from parity x emotion valence ANOVA, and parity x reactivity ANOVA

Measure	Sum Sq	df	Mean Sq	*F*-value	*p*-value	η2
2 x 3 ANOVA for LPP amplitudes (excluding other mental disorders)						
Parity	0	1	0.17	0.004	0.949	12.08e-05
Emotion valence	3851	2	1925.7	366.401	2<e-16***	0.65
Emotion valence x Parity	30	2	15.2	2.898	0.0563*	0.01
Between-subjects error	8185	198	41.34			
Within-subjectss error	2081	396	5.3			
2 x 3 ANOVA for LPP amplitudes (excluding participants from QC)						
Parity	2	1	1.61	0.038	0.846	1.74e-04
Emotion valence	4170	2	2085.2	417.659	<2e-16***	0.66
Emotion valence x Parity	34	2	17.1	3.433	0.0332*	0.02
Between-subjects error	9217	218	42.28			
Within-subjects error	2177	436	5.0			
2 x 2 ANOVA for reactivity scores (excluding other mental disorders)						
Parity	87	1	86.68	5.165	0.0241*	0.03
Emotion valence	377.6	1	377.6	76.806	8.52e-16***	0.28
Emotion valence x Parity	1.6	1	1.6	0.318	0.573	1.61e-03
Between-subjects error	3323	198	16.78			
Within-subjects error	973.5	198	4.9			
2 x 2 ANOVA for reactivity scores (excluding participants from QC)						
Parity	100	1	99.96	6.234	0.0133*	0.03
Emotion valence	370.5	1	370.5	79.837	<2e-16***	0.27

Emotion valence x Parity	1	1	1	0.207	0.65
Between-subjects error	3495	218	16.03		
Within-subjects error	1011.7	218	4.6		