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REVIEW OF INFANT EEG STUDIES IN THE CONTEXT OF MATERNAL DEPRESSION AND ANXIETY

Syventävien opintojen kirjallinen työ

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The environmental factors during pregnancy and early childhood affect development of individual in various manners. This review considers maternal perinatal depression and anxiety and their influences on offspring determined with electroencephalography (EEG) that measures the electrical activity of brain, either by observing EEG asymmetry or more specific, time linked components called event-related potentials (ERPs). The aim of this review is to raise the significance of maternal mental wellbeing and its effects in infant brain function and development, and also observe the possibilities of EEG as a tool in this study field.

This review contains summaries and conclusions of 7 articles. To pick the articles, the following search phrase was used in PubMed: “EEG AND (infants or newborns or children) AND (brain or neuroimaging) AND emotion” and it yielded 424 articles. 20 of them were EEG studies and considered influences of maternal depression and/or anxiety on offspring’s neural responses measured by EEG. From this sample I chose 8 on the grounds of the age of test subjects (neonates to 17-month-olds) and ultimately 7 articles were included.

This is not a systematic review as all the studies are relatively different with each other but together they do provide evidence for the likely negative influences of maternal perinatal stress on offspring. Across all the studies they found differences between infants that were perinatally exposed to maternal depression or anxiety and infants that were not. These studies also prove that EEG is suitable and usable method to perceive these influences.

Keywords: EEG, maternal depression, maternal anxiety

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1 INTRODUCTION

1.1 Prenatal stress

Factors, such as prenatal stress, are known to modify brain already during the embryonic development ¹. Despite many facets of stress, prenatal stress is frequently defined as maternal depression and/or anxiety that are related to child deviant behavioural, emotional and cognitive development as well as an elevated risk for certain somatic medical conditions ². The studies in this review consider both maternal depression and anxiety, during and after pregnancy. Most studies measured 11-17 months after pregnancy depending on the age of the participating child. Of course, it is possible and even likely that at least a part of these mothers were depressed already during the pregnancy but child's "prenatal exposure to depression" is not specifically determined or in the centre of these studies.

1.2 EEG

Electroencephalography (EEG) is very well-known, much used and applicable to many studies and age groups. EEG measures the electrical activity of brain from standard measurement electrode positions. From these signals one can estimate more specific, time linked components called event-related potentials (ERPs) ³ or EEG asymmetry which means comparison of the most active skull locations in different conditions ⁴.

Event-related potentials are stimulus-time-linked electric reactions generated by big populations of neurons ³. Temporal variation of these ERPs takes place on milliseconds time scale. So, ERPs are always responses for a stimulus, but the stimulus can be external (e.g. heard sound) or internal (e.g. reactive motor task). They consist of many different positive and negative wavelike components and peaks that can be identified and named by their time of appearance and polarity. For example, N1 means first negative poststimulus wave and P2 second positive ³. They can also be named according to direct time of appearance so that for instance P300 component means a positive wave that peaks at 300 ms after a stimulus ³. Third way of nomination is based on event properties from which a positive slow wave (PSW) is a good example ³.

ERPs are related with sensory, motor and cognitive processing. Sensory ERPs are evoked by an external stimulus, so they are called exogenous. Stimuli can be visual, auditory or

somatosensory and they can be measured with electrodes placed in proximity of these sensory cortices respectively³. Motor ERPs are elicited by internal movement-related events like preparing for muscle contraction and so they are called endogenous³. Cognitive components are related to cognitive processes and they are considered endogenous as well. In EEG asymmetry studies, it is commonly inferred that left frontal region of brain is associated with expressions of positive/approach emotions while right frontal region is associated with negative/withdrawal emotions⁴.

With appropriate conditions and procedure EEG can be very accurate and reliable method due to its sensitivity. On the other hand, because of that sensitivity, a lot of noise is always recorded along with the object signal. Any contribution to recording that is not from the signal source is considered as noise³. Comparing to the techniques in which the electrodes are placed inside the head instead of the surface of the scalp the signal is obviously powerless, but there's no need to argue that of course it's a huge advantage that EEG is measured noninvasively and safely³.

1.3 Depression

The core symptoms of diagnostic depression are depressed state of mind, loss of an experience of pleasure and continuous fatigue⁵. Other possible symptoms are self-doubt, excessive self-criticism and baseless feel of guilty, suicidal thinking or behaviour, lack of concentration, psychomotor slowness or agitation, sleep disturbances and changes in appetite⁵. Severity of depression can be classified as slight, moderate, severe or psychotic and a patient's ability to act is usually in proportion to severity of the state. Depression can be treated with psychotherapy and/or medication depending on its severity and patient's own wishes⁶. Pharmaceutical treatment is always recommended when talking about severe and psychotic depression states. On the other hand, the medication should never be the only form of care as there should be always a good doctor – patient relationship and someone to approach and deal the issues behind the depression with. In Europe, the annual prevalence of depression has varied between 3 and 10 % depending on the country and the study⁷. In Finland about 5 % of population has been estimated suffering from depression during a year, which can be regarded as average European prevalence⁷. Pregnancy and first postnatal year are for woman the most likely times to get depressed⁸. In previous research

10-15 % of pregnant women have been estimated suffering from depressive symptoms ⁹ and there seems to be an increasing trend, in a prevalence of prenatal maternal depression ⁹.

Because depression is a major problem in the society it would be extremely important to find still better manners to prevent it in the first place. It is known that there are a lot of situations that make an individual more dispose to depression. Many of these issues can be found in childhood as severe stress factors during early life can modify nerve pathways and hormonal stress responses for longer term ¹⁰. Examples of these severe stress factors could be death or illness of a family member or child maltreatment like physical abuse, emotional neglect or sexual abuse. Of course, all depressed people don't have this kind of history and all people with this history don't become depressed as there are multiple genetic, environmental and other factors contributing as well. Maternal mental health status during and after pregnancy is one of these factors that need more specific examination and examples of this research.

1.4 Anxiety

Anxiety disorders are the most common group of mental disorders and it covers many different problems and diagnoses in which typical symptoms are continuous nervousness and worrying, panic, phobias, activation of autonomic nervous system and avoidance behaviour towards things that provoke these feelings and experiences ¹¹. The most well-known manifestations of anxiety disorders are generalized anxiety disorder, panic disorder, social phobia, other specific phobias and obsessive-compulsive disorder ¹¹. Anxiety is not only a disorder but also a part of normal life and it is not always easy to make difference between normal and pathological anxiety and stress. For pathological anxiety it is required that it is continuous and considerably complicates everyday life and causes distress. The type of pathological anxiety is not always easy to define in one specific diagnosis as there are often characteristics from more than one disorder. When talking about pathological chronic and diffuse anxiety with many different kinds of worries we often discuss generalized anxiety disorder ¹².

Genetic factors have been represented to play a very important role for generalized anxiety disorder especially in women ¹². Tendency to be anxious and worry a lot can cause pregnancy to be stressful time as there are so many life changes becoming and so much to

worry about for the future baby. Anxiety during pregnancy can be generalized or more specific to pregnancy¹³. Because this phenomenon exists, and we know that being anxious during pregnancy can actually have a negative influence on offspring we need more research and interventions to prevent this anxiety and its possible deleterious consequences¹³.

1.5 Current review

This review contains brief summaries and conclusions of 7 articles that consider brain function of infants and that function has been determined with EEG. All the studies include two groups of children: case and comparison. 4 studies focus on maternal depression and EEG asymmetry while 3 studies focus on pre- and perinatal maternal anxiety and ERPs.

The aim of this review is to raise the significance and importance of such environmental factors as maternal mental state during pregnancy and early childhood in the development of regulation mechanisms of emotions and also observe the possibilities of EEG as a tool in this study field. This is not a systematic review as all the studies have a little bit different context, approaches and hypotheses but it rather supposed to offer a glance to this research field and the possibilities of EEG in it.

The environmental factors during pregnancy and early childhood affect development of individual in various manners¹⁴. This review considers the influences of maternal mental wellbeing on EEG responses in infants. The research in this field aims to investigate and determine mechanisms by which these factors modify brain, and paths by which these modifications affect the character and behaviour of individual and also the risk of variety of psychiatric and other disorders.

METHODS

PubMed was used to identify the articles used in the review. To pick the studies for this review, the following search phrase was used: “EEG AND (infants or newborns or children) AND (brain or neuroimaging) AND emotion” and it yielded 424 articles (31.5.2018). 20 of them were EEG studies and considered influences of maternal depression and/or anxiety on offspring’s neural responses in different conditions measured by EEG. From this sample of 20 articles I chose 8 on the grounds of the age of test subjects. In these studies, all the test

subjects were infants from neonates to 17-month-olds whereas in other studies the subjects were considerably older. Ultimately 7 articles were included in this review.

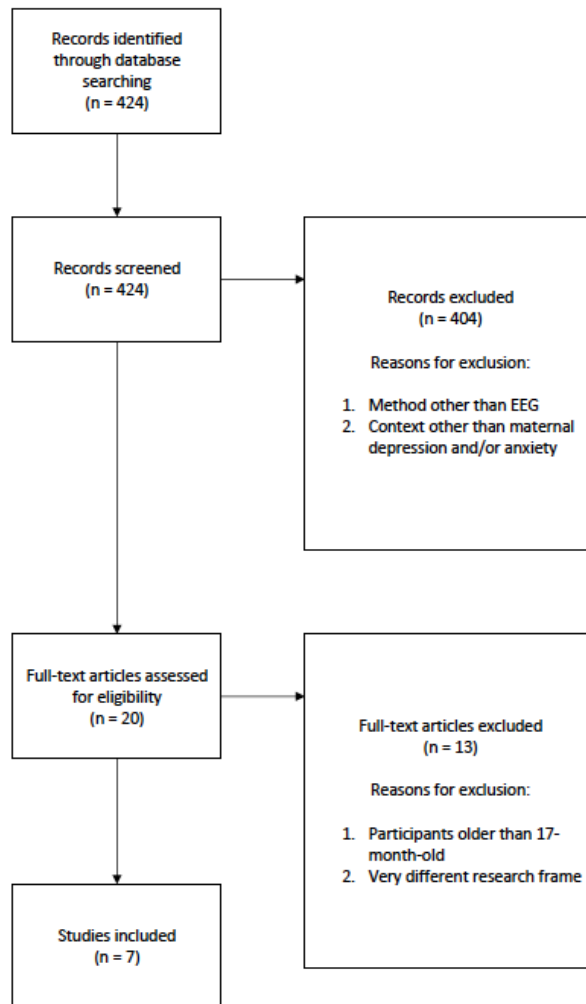


Figure 1 Study selection process

All the studies in this review were performed between 1992 and 2015. The first four of them consider mainly maternal depression measured after pregnancy while the last three consider mainly maternal pre- and perinatal anxiety. The youngest infants were neonates (Harvison et al., 2009)¹⁵ and the oldest were 17-month-olds (Dawson et al., 1992, 1997)^{16 17}. The number of participants of the study varied from 27 (Dawson et al., 1992)¹⁶ to 117 (Dawson et al., 1997)¹⁸. All the measurements were performed with EEG.

3 RESULTS

3.1 Maternal depression and EEG asymmetry

First article in this review was “Frontal Lobe Activity and Affective Behavior of Infants of Mothers with Depressive Symptoms” (Dawson et al.)¹⁶, published in 1992 in *Child Development*. In this study, they examined 27 11-17-month-old infants of mothers with and without depressive symptoms during baseline condition and emotional contexts by measuring the infants’ brain activity with EEG. They hypothesized that infants of mothers with depressive symptoms (case) would show reduced left frontal EEG activity during play with mother and reduced right frontal activity during maternal separation, compared to the infants of nonsymptomatic mothers (control).

Maternal age varied from 15 to 21 years. Differences in characteristics between case and control mothers were nonsignificant except for marital status as significantly more case mothers were married. During the baseline condition infants observed bubbles cascading behind the curtain. In the first emotional condition, infants viewed a videotape that included happy, sad and neutral affects. In the next condition, mothers played peek-a-boo with their infants. Next, a stranger entered the room, walk toward the infant displaying neutral affect, loomed the infant and then left the room. In the last condition, mothers were asked to wave goodbye, walk slowly towards the door and then leave the room. Infants were videotaped during the measurement and EEG was recorded with gold cup electrodes from left and right frontal and left and right parietal sites, according to International 10-20 system.

As they hypothesized, during the playful condition, infants of control mothers showed greater left versus right hemisphere activation while infants of case mothers failed to show differential hemisphere activation. During the Mother Away condition, infants of case mothers showed greater left versus right hemisphere activation and infants of controls did not show differential hemisphere activation. Infants of case mothers also showed reduced distress during the maternal separation. During the playful condition, there were no group differences in behaviour. All group differences were specific to frontal but not parietal brain activity.

The second article “Infants of Depressed and Nondepressed Mothers Exhibit Differences in Frontal Brain Electrical Activity During the Expression of Negative Emotions” (Dawson et al.)¹⁷ was published in 1997 in *Developmental Psychology*. In this study, they examined electrical brain activity during negative, positive and neutral emotions in 30 11-17-month-old infants of depressed (case) and nondepressed (control) mothers. They hypothesized that infants of case mothers would exhibit increased frontal EEG activation during negative emotional expressions and possibly decreased frontal activation during positive emotional expressions. They did not take a stand on if these differences would be specific to one hemisphere or not and which one.

Maternal age varied from 15 to 21 years. Infants of case mothers were one month older, on average, than infants of control mothers and case mothers were more likely to be married, compared to controls. During the measurement, infants were being exposed to conditions designed to bring about different emotions: bubbles cascading, mother playing, stranger entering the room, mother waving goodbye while leaving the room and finally mother returning. Infants were videotaped in order to observe and qualify their facial expressions. EEG was recorded with gold cup electrodes in according to International 10/20 system from four scalp locations: left and right, frontal and parietal.

There were no differences between infants of case and control mothers for conditions eliciting positive emotions (surprise and happiness). However, there were region and hemisphere differences as for surprise condition the parietal areas were activated more than the frontal areas, and the left hemisphere was more activated than the right. For happiness the left hemisphere was activated more than the right. For negative emotions (unfelt smiles and anger), there was a difference between infants of case and control mothers as infants of case mothers exhibited greater activation of the frontal region. Also, for unfelt smiles, the frontal region was more activated than the parietal and the left hemisphere was more activated than the right. For anger the same effect of hemisphere was marginally significant. For neutral expressions, the parietal region was more activated than the frontal and the left hemisphere was more activated than the right. No significant differences between infants of case and control mothers were found but infants of case group actually exhibited reduced frontal EEG activity compared to infants of control mothers, during neutral expressions.

The third study was “Infants of Depressed Mothers Exhibit Atypical Frontal Brain Activity: A Replication and Extension of Previous Findings” (Dawson et al. 1997, *J Child Psychol Psychiatry*)¹⁸. In this study, they compared baseline frontal and parietal brain activity between 117 13-15-month-old infants of depressed (case) and nondepressed (control) mothers, by EEG measurements. They hypothesized that infants of case mothers would exhibit reduced left frontal brain activity.

Case mothers were 2 years older on average (ms 32 and 29.9 years) and they also were less likely to be married, compared to control mothers. These differences were used as covariates. Groups of infants did not significantly differ in terms of age, gender, birth order or average time spent per week in day-care. EEG was recorded during a 1-minute baseline period while infants was seated on a chair across a black curtain behind which bubbles were cascading in order to sustain the interest of infant. Infants’ affective behaviour during recording was videotaped. EEG was recorded in according to International 10/20 system from four scalp locations: left and right, frontal and parietal.

As they hypothesized, infants of case mothers exhibited reduced left frontal brain activity compared to the infants of control mothers. They found also a linear relationship between infant EEG and the severity of maternal depression as infants of mothers with more severe depression showed lower levels of left frontal EEG activity than infants of mothers with subthreshold depression. The chronicity of postpartum depression was also predicative to infant’s frontal activity. EEG asymmetry scores did not differ at the parietal sites. Infants of case and control mothers showed identical affective behaviour during the recording and it’s therefore unlikely that differences in EEG in asymmetry scores are related to infant’s affective behaviour. BSI (Brief Symptom Inventory) anxiety and hostility scores were also controlled, and these variables were not found to be related to infants’ frontal EEG asymmetry scores which suggests that atypical findings were specifically associated with maternal depression rather than other mental health problems.

“Infants of Depressed Mothers Exhibit Atypical Frontal Electrical Brain Activity during Interactions with Mother and with a Familiar, Nondepressed adult” (Dawson et al.)¹⁹ was published in 1999 in *Child Development*. The aim of this study was to provide further evidence for previous studies suggesting that infants of depressed mothers exhibit atypical

frontal brain electrical activity while they are in social contact with their mothers, and also to investigate whether the atypical pattern is elicited in conditions not involving mother too. The final sample consisted of 99 13-15-month-olds infants of depressed (case) and nondepressed (control) mothers.

Case mothers were 30.5 years on average while control mothers were 29.3 years on average. The groups did not differ in relevant background terms except the marital status in the way that control mothers were more likely to be married compared to case mothers. This difference was used as a covariate. Infants of case mothers also showed slightly more reaction to food compared to the children of control mothers. Maternal anxiety was also used as a covariate in order to determine the specificity of depression behind the possible findings. The study included five different experimental social conditions: baseline condition, mother play, stranger approach, familiar experimenter play and mother separate. EEG was recorded in according to International 10/20 system from four scalp locations: frontal and parietal, left and right. Affective behavior during recording was videotaped in order to separate positive and negative affect.

Across all positive affect experimental conditions (baseline, mother play, familiar experimental play) infants of case mothers displayed reduced left relative to right frontal EEG activity compared to infants of control mothers. For both groups, the familiar experimenter play condition was showed with increased left frontal activity compared to the other conditions. Across negative affect conditions (stranger approach, mother separate) no significant effects or interactions was found for frontal activity. As an unpredicted finding, during the stranger approach infants of control mothers showed greater right relative to left EEG activity at the parietal sites, while infants of case mothers displayed the opposite pattern. Maternal anxiety had no significant influence on infants' EEG patterns.

3.2 Maternal anxiety and ERPs

The next article "Neonatal auditory evoked responses are related to perinatal maternal anxiety" (Harvison et al.)¹⁵ was published 10 years later than the previous one (2009, Brain and Cognition) and instead of maternal depression it focuses on maternal anxiety during and immediately after pregnancy. In this study, they examined the relationships between

perinatal maternal anxiety and neonatal AERs (auditory evoked responses) to mother and stranger voices.

The final sample consisted of 28 mother-neonate dyads. Perinatal maternal anxiety was measured by using self-report measure of anxiety severity. Anxiety was measured during the final week of gestation and 1-2 days immediately following the birth. Mothers' voices were recorded the evening before the neonate testing and the stranger voice used was the voice of the previous mother in the sample. The stimulus consisted of words "bidu" and "gibu" and it included 120 trials in total in a randomized order. EEG was recorded with 129 silver/chloride plated carbon pellet electrodes.

The anxiety measurement of mothers yielded 17 low-anxiety (control) and 11 high-anxiety (case) mothers. Neonates of control mothers displayed more negative frontal slow wave amplitudes in response to their mother's voice compared to the stranger's voice whether in the group of neonates of case mothers the opposite pattern was observed. The mothers in the control group were slightly older, had delivered more children and had higher income levels. In addition to being anxiogenic to the mother, these factors could also have more direct effects to the developing fetus. The offspring of both mothers had equivalent outcomes on major obstetric variables including birth weight, APGAR score and type of delivery.

Traditionally studies in this field have examined negative states and their influences and relatively little is known about maternal well-being and its possible positive effects on offspring. "Maternal mindfulness and anxiety during pregnancy affects infants' neural responses to sounds" (Van de Heuvel et al. 2015, *Social Cognitive and Affective Neuroscience*)²⁰ considers maternal mindfulness that is thought to be one example of these positive mental factors. Being mindful means to have an alert mode of perceiving of the present moment, all kind of feelings and thoughts and also have an accepting and non-judgemental attitude towards them ²⁰. In this study, they examined the effects of maternal mindfulness and anxiety during pregnancy on the infants neurocognitive functioning at the age of 9 months. They hypothesized that maternal mindfulness and anxiety would affect the offspring in opposite ways.

The final sample consisted of 78 mothers and their 79 infants (42 girls, one pair of twins). Prenatal maternal mindfulness and anxiety were measured with questionnaires at the beginning of the second semester and postnatal anxiety 10 months after birth. ERPs were measured 9 months after birth (mean age 43.90 weeks) in a passive auditory oddball paradigm. The stimulus consisted of four different types of sounds: a frequent standard (probability 0.7) and three types of infrequent deviant sounds (each with a probability of 0.1). ERPs were recorded using caps with 64-electrode locations placed according to the International 10-20 system. Camera recordings were used to exclude episodes where the infant was crying or moving.

Maternal mindfulness and anxiety during pregnancy were negatively correlated as expected. Also, prenatal and postnatal anxiety were positively correlated. For the ERPs elicited by standard sounds, higher maternal mindfulness was associated with lower N250 amplitudes while higher maternal anxiety was associated with larger N250 amplitudes. In addition, maternal mindfulness was positively associated with P150 amplitudes, for the standard sounds. There were no significant associations for the deviant stimuli as the opposite patterns between maternal mindfulness and anxiety were found only for the standard sounds. Neither postnatal maternal anxiety was significantly associated with the measured ERP amplitudes.

The last article "Multimodal processing of emotional information in 9-month-old infants II: Prenatal exposure to maternal anxiety" (R.A. Otte et al.)²¹ was published in 2015 in *Brain and Cognition*. In this study they investigated multimodal processing of fearful and happy face/voice pairs in 9-month-olds exposed to prenatal maternal anxiety by using ERPs (event related potentials). They hypothesised that higher levels of anxiety during pregnancy would be associated with larger responses to fearful auditory stimuli and would most strongly affect responses to auditory stimuli which had been preceded by visual stimuli conveying the same emotion.

Subjects were 82 infants (including one pair of twins) and their mothers. As visual stimuli they used 18 colour photos of 9 women in frontal view, each expressing both happiness and fear. Auditory stimuli were voice recordings of 6 women expressing happiness and fear with non-verbal vocalisations. Happy and fearful vocalisations had preceded by happy or fearful

facial expressions. For EEG recording they used head caps with 64 electrode locations positioned according to the revised version of the 10-20 system. Continuous predictor variables were state anxiety and more generalised anxiety.

They found larger P350 amplitudes in response to fearful vocalisations when infants had been exposed to higher levels of maternal anxiety. The type of visual prime preceding wasn't significant. There was also a positive association between P150 amplitudes and anxiety scores. There were no significant effects involving state anxiety and therefore only findings for generalised anxiety were reported in the study. For the P350 they found an association between the level of maternal anxiety and processing of emotional vocalisations. Also, for the P150 and N450 they found associations between the level of maternal anxiety and processing of emotional vocalisations that trended towards significance. The results confirmed their first hypothesis that higher levels of maternal anxiety are associated with larger responses to fearful auditory stimuli. For their second hypothesis, that the association between exposure to maternal anxiety and responses to the audiovisual stimuli conveying the same emotional information, the study did not provide evidence.

ARTICLE	YEAR	1st AUTHOR	JOURNAL	AGE	N	CONTEXT	STIMULI	RESULT SUMMARY
Frontal Lobe Activity and Affective Behavior of Infants of Mothers with Depressive Symptoms	1992	Geraldine Dawson	Child Development	11-17-month-olds	27	depression	conditions designed to bring about different emotions	Infants of depressed mothers showed greater left versus right hemisphere activation during the maternal separation and failed to show differential hemisphere activation during the playful condition and also showed reduced distress during the maternal separation
Infants of Depressed and Nondepressed Mothers Exhibit Differences in Frontal Brain Electrical Activity During the Expression of Negative Emotions	1997	Geraldine Dawson	Developmental Psychology	11-17-month-olds	30	depression	conditions designed to bring about different emotions	Infants of depressed mothers exhibit increased frontal brain activation during negative emotional expressions
Infants of Depressed Mothers Exhibit Atypical Frontal Brain Activity: A Replication and Extension of Previous Findings	1997	Geraldine Dawson	J Child Psychol Psychiatry	13-15-month-olds	117	depression	baseline condition	Infants of depressed mothers exhibited reduced left frontal brain activity compared to the infants of nondepressed mothers; they found also a linear relationship between infant EEG and the severity of maternal depression
Infants of Depressed Mothers Exhibit Atypical Frontal Electrical Brain Activity during Interactions with Mother and with a Familiar, Nondepressed Adult	1999	Geraldine Dawson	Child Development	13-15-month-olds	99	depression	conditions designed to bring about different emotions	Infants of depressed mothers exhibited reduced left relative to right frontal brain activity during the baseline and positive conditions, not only in contact with mother but also in contact with an adult other than mother
Neonatal auditory evoke responses are related to perinatal maternal anxiety	2009	Kyle W. Hanvson	Brain and Cognition	Neonates	28	anxiety	mothers/stranger's voice	Neonates of low-anxiety mothers showed more negative frontal slow wave amplitudes in response to their mother's voice compared to the stranger's voice while neonates of high-anxiety mothers showed the opposite pattern
Maternal mindfulness and anxiety during pregnancy affect infants' neural responses to sounds	2015	Marion I. Van den Heuvel	Social Cognitive and Affective Neuroscience	9-month-olds	79	anxiety, mindfulness	frequent standard and infrequent deviant sounds	Higher maternal anxiety was associated with higher N250 amplitudes when maternal mindfulness was associated with lower N250 amplitudes and positively associated with P150 amplitudes, these results were found only for the standard sounds
Multimodal processing of emotional information in 9-month-old infants II: Prenatal exposure to maternal anxiety	2015	R.A. Otte	Brain and Cognition	9-month-olds	82	anxiety	emotional face and voice expressions	Higher levels of maternal anxiety are associated with larger responses to fearful auditory stimuli

Table 1 Study characteristics and result summaries

4 DISCUSSION

Despite the fact that all the studies included in this review are relatively different with each other, together they do provide evidence for the likely negative influences of maternal perinatal depression and anxiety on offspring as across all the studies they found differences between infants that were perinatally exposed to maternal depression or anxiety and infants that were not. They also prove that EEG is a suitable and usable method to noninvasively perceive these influences.

First four studies focused on maternal depression. These studies also focused on EEG electrical asymmetry comparing infants' left and right cortical activation during baseline and emotional conditions. Left frontal region is related to positive emotions while right frontal region is related to negative emotions ⁴.

The first four studies considered brain function of infants of depressed (case) and nondepressed (control) mothers. In the first study infants of case mothers showed reduced left frontal EEG activity during a playful condition compared to the infants of control mothers ¹⁶. Also, infants of case mothers showed greater left versus right hemisphere activation and reduced distress during a mother separate condition ¹⁶. In the second study, infants of case mothers exhibited increased frontal EEG activation during negative emotional expressions which may suggest that these infants tend to express negative emotions more intensively ¹⁷. In the third study infants of case mothers exhibited reduced left frontal brain activation during a baseline condition with a linear relationship between maternal depression and infant EEG, that can be related to early pattern of depressive symptoms ¹⁸. In the fourth study infants of case mothers showed reduced left relative to right frontal EEG activity compared to the infants of control mothers across all positive conditions ¹⁹. All studies together suggest that exposure to maternal depression can affect offspring's brain function and processing of emotions across both positive and negative emotional as well as neutral conditions.

The last three studies focused on pre- and perinatal maternal anxiety. In the first study of these, infants of low-anxiety mothers displayed more negative frontal slow wave amplitudes in response to their mother's versus stranger's voice while the infants of high anxiety

mothers showed the opposite pattern ¹⁵. The second study focused not only on prenatal maternal anxiety but also on prenatal maternal mindfulness. Maternal anxiety and mindfulness were negatively correlated, and they found opposite effects between anxiety and mindfulness in infants' neural responses for the standard sounds ²⁰. The fact that these opposite patterns were found only for the frequent standard sounds may suggest that the infants prenatally exposed to higher level of maternal mindfulness devote fewer attentional resources to frequently occurring irrelevant sounds ²⁰. In the last study infants exposed to higher levels of maternal anxiety during pregnancy showed larger responses to fearful auditory stimuli ²¹. This may indicate increased attention and more extensive processing of fear-related stimuli with infants that have been exposed to higher levels of maternal anxiety ²¹.

It is partly unclear which of these offspring outcomes are results of prenatal and which postnatal maternal mental or other conditions. It is known, that postnatal maternal depression influences on interaction between mother and infant, and infant may adopt depressive interaction model to other relationships too ²². As an example, in the fourth study of this review infants of depressed mothers showed altered brain function not only in contact with their mother but also in contact with a familiar, nondepressed adult other than mother ¹⁹.

Of course, besides maternal mental health status there are many other early life factors and circumstances that modify developing brain. Hardship in early life, like child maltreatment, will definitely have a negative influence on child development and can make an individual more vulnerable later in life. EEG too has been one crucial technique for measuring these effects in the brain and determine possible mechanisms behind them. Dante Cicchetti and W. John Curtis (2005)²³ examined young children's neural responses to happy, angry and neutral facial expressions with EEG. Results in their study suggest that maltreated children may allocate more attention to anger and also that their ability to recognize emotions may be decreased ²³.

What it comes to maternal mindfulness, it is very interesting and refreshing to see results in which a maternal mental state during pregnancy actually may induce a possible positive influence on offspring because a research in this field has almost exclusively focused on

negative states and traits. Highly anxious mothers can feel guilty about the information that being anxious during pregnancy could affect their future child in a negative way and that can actually promote even higher anxiety, thus it could be more fruitful to emphasize the potential of mindfulness and its possible positive effects to them instead ²⁰. In addition, the possible benefits of mindfulness intervention could be kept in mind concerning all pregnant women achieving even healthier pregnancy.

5 CONCLUSIONS

As a conclusion considering all the studies in this review, effects of maternal depression and maternal peri- and prenatal anxiety can be found when measuring infants' brain activity and function with EEG. What is not that clear is which of these phenomena are actually consequences of maternal mental states and which consequences of other factors such as genetic regulators and postnatal environmental differences other than maternal mental health status ². The more specific knowledge of these mechanisms and paths by which these early life factors modify brain would be extremely important to prevent possible negative influences on developing brain. Alterations in maternal hypothalamus-pituitary-adrenal (HPA) axis functioning and increased hormone cortisol secretion during pregnancy are the most studied mechanisms underlying prenatal stress ². However, connection between HPA axis alterations and offspring outcomes has not been succeeded to prove in many studies ². Other stress-moderating pathways as alterations in the immune system, placenta or gut microbiota should bear in mind within the further research, that is needed ². It would be especially informative to perform longitudinal studies. One ongoing comprehensive study under this research field is FinnBrain Birth Cohort Study ² that was set up in 2010 to study prospectively the effects of prenatal stress in its possible long-term influences, such as mental and other health problems and stages towards them, in order to have better tools to prevent them too.

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