UNIVERSITÉ DE LORRAINE

FACULTÉ DE MÉDECINE / MAÏEUTIQUE / MÉTIERS DE LA SANTÉ à NANCY

Département Universitaire de Maïeutique

Diplôme d'État de Sage-Femme

Mémoire de fin d'études présenté et soutenu par

Anaïs BAGUE MORANDINI

Adaptations anatomiques cérébrales générées par la grossesse, une revue systématique de littérature.

Articles de 1984 à 2021.

Soutenu en 2022

Directeur de mémoire : Léonore AVERCENC

Sage-femme, Docteure en Sciences de la Vie et de la Santé

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REMERCIEMENTS

On ne sait combien notre mère nous chérit d'amour

que lorsque nous devenons maman à notre tour.

C'est l'Amour, véritable, incommensurable et inébranlable.

Autrefois je ne vivais que pour moi, aujourd'hui je ne vis que pour eux

Lorsqu'un enfant vient au monde, il y a deux naissances : celle du bébé et celle de sa mère.

Je dédie ce mémoire à mon mari, ma famille et mes amis, qui m'ont soutenue dans cette nouvelle vocation d'accoucheuse, mais aussi et surtout à mes enfants Gaël et Faustine qui m'ont permis de m'accomplir en tant que mère.

Je remercie également Madame Avercenc de m'avoir guidée et soutenue dans ce travail si laborieux.

SOMMAIRE

LISTE DES ABREVIATIONS

- Â = middle age
- ACC = anterior cingulate cortex
- ant = anterior
- BA = Brodmann area
- caud = caudate
- cing = cingulate
- CTX = cortex
- D = day
- dmPFC = dorsomedial PFC
- (E) = early
- F = female
- fMRI = functional MRI
- front = frontal
- GI = gyrification index
- GM = grey matter
- H = hour
- hippo = hippocampus
- hypothal = hypothalamus
- inf = inferior
- (I) = immediate
- L = left hemisphere
- lat = lateral
- (L) = late
- M = months
- med = medial
- mPFC = medial PFC
- mid = middle
- MPAS = maternal postnatal attachment scale
- MRI = magnetic resonance imagery
- multi = multigeste (two or more times been pregnant)/multiparous woman (two or more children)
- nulli = nulligeste (who never have been pregnant)/nulliparous woman (who never gave birth)
- occ = occipital
- pariet = parietal
- PCC = posterior cingulate cortex
- PFC = prefrontal cortex
- PG = pituitary gland
- post = posterior
- postcent = postcentral
- PP = postpartum
- precent = precentral
- primi = primigeste/primiparous woman (only one child)
- Py = pregnancy
- ROI = region of interest
- SMA = supplementary motor cortex
- sup = superior
- STS = superior temporal sulcus
- temp = temporal
- TPJ = temporoparietal junction
- thal = thalamus
- vmPFC = ventromedial PFC
- W = week
- WM = white matter
- Y = year
- ↗ = increase
- ↘ = decrease

ARTICLE

ANATOMICAL BRAIN ADAPTATIONS GENERATED BY PREGNANCY, A SYSTEMATIC REVIEW OF LITERATURE.

ARTICLES FROM 1984 TO 2021.

Anaïs BAGUE MORANDINI[1] and Léonore AVERCENC[2]

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ABSTRACT

Background : The maternal brain is the seat of many hormonal, cognitive and psychological adaptations during pregnancy and postpartum. More recently, studies have shown brain anatomical changes during this particular period of women's lives.

Objective(s) : This review aimed to compile knowledge on the anatomical adaptations of the maternal brain during pregnancy and postpartum. The secondary objectives were to highlight the moment of emergence and the duration of these modifications, what and how cerebral functions are impacted, and finally their link with maternal behaviors and cognitive functions.

Method : This systematic review was conducted under the PRISMA 2020 model. Keywords such as neuronal plasticity, pregnancy and maternal behavior were used on different databases such as NCBI or PLOS. Eighteen articles from which data (type of study, quality, composition of groups, frequency of measurements, brain regions impacted, etc.) were extracted.

Results : The data show that the pituitary gland increases in size during pregnancy, while other cerebral structures such as the cortex, the basal ganglia, the cerebellum, the hippocampus, the thalamus or the hypothalamus decrease in volume . These modifications improve the memory performance, social qualities and caregiving skills of mothers. It seems that these adaptations persist for several months or even years after birth according to some studies, other research teams otherwise disagree with this conclusion.

Conclusion : Regarding changes during the postpartum period, the conclusions of the included studies are contradictory in terms of growth or decrease in volumes and the persistence or regression of these adaptations. In any case, we cannot conclude that there is a loss of cerebral substance, not knowing the underlying mechanisms or the cell density of the impacted structures, but it is certain that there is in reality little or no reduction in capacity cognitive, on the contrary.

Keywords : brain plasticity, pregnancy, postpartum, maternal behavior

INTRODUCTION

Under reproductive hormones, the expectant woman's organism, including the brain, is the seat of many modifications in physiology, immunology, endocrinology and metabolism (1,2). Mainly due to oxytocin and prolactin, the future mother's body adapts to the pregnancy to allow the development of embryo then fetus for nine months, and after birth, to offer the newborn tailored milk thanks to breastfeeding (3,4). Women also need psychic maturation called "matrescence" (Dana Raphael, 1973) to take on their new identity and challenging role, giving "birth" to a mother. The process of motherhood is essential for the survival of many species as newborn animals, especially human toddlers, are dependent on adults. Consequently, parents have to create bonds with infants, understand them, decode their crying cues and provide them the care they need to survive and grow (5-7).

Papers on human neuronal plasticity involved in brain function of maternal response during the postpartum (PP) period highlight the existence of brain maternal circuits essential to the mother-child bond creation and good mental health of the new mothers (8-11). Perinatal period is a fragile psychologic moment for expecting women and young mothers. Many studies on perinatal psychiatric illnesses have been carried out to understand their inherent causes, and reviews concerning mothers' brain structure suffering from PP depression (12), anxiety disorder (13), maternal burn-out (14), psychosis (15), and even on pregnant women's dreams (16) were published. Notably to allow the scientific societies to edit recommendations of good practices for health providers in order to better support mothers. Otherwise, there is an old popular belief that expectant women and news mothers lose neurons, which would lead to the memory and concentration impairments commonly observed during pregnancy and first PP months, situations named "baby brain" because of this sort of cognitive regression, or "mommy brain" in reason of the focalization of the mother for the newborn cares and attachment (17,18).

However, physical adaptations of the entire brain, in psychically well mothers, are unrecognized. Before 1990, six papers merely focused on women's pituitary modifications due to pregnancy, four of them were postmortem studies, on deceased ladies due to accidental causes or gestational pathologies. Cerebral autopsies revealed a bigger pituitary gland (PG) in expectant women, the biggest in multiparous mothers, by a count rising of "pregnancy cells" which are located in anterior hypophysis and produce prolactin in growing amounts during pregnancy and breastfeeding. This change tooks some months to regress, but not totally in mothers of several children (19-22). Between 1990 and 2000, two articles explored dimensions and shape of hypophysis during pregnancy and PP but on women with cerebral diseases. PG increases regularly in volume, mostly in width and in convexity of the upper side, along all gestation duration, reaching a maximum at day 0-3 after birth. Then it decreases rapidly after one week with a normal size recovered at an average of two months. No difference was found between lactating and non-lactating mothers (23,24).

The first team to take an interest in the brain as a whole was Oatridge A *et al.* in 2002 (25), that proved an actual cerebral volume diminution by expectant women, with a return to normal at 9th month PP. Studies on alive and healthy pregnant women and mothers were rare before 2010 and have known a real infatuation since but were only of cohort or cross-sectional type with magnetic resonance imaging (MRI) because of obvious ethical barriers and implementation difficulties. They showed sometimes contradictory results.

By the action of gestation hormones, brain networks implicated in maternal behaviors, like the Theory of Mind (ToM) or the Default Mode Network (DMN), are reshaped and shrinked, making them more efficient (26,27). They have been shown giving mothers a kind of emotional clairvoyance and social intelligence, greater empathy, ability to be at tuning fork of their babies after birth, and better appreciation of mother-child relationship and attachment quality. Cellular mechanisms of brain plasticity aren't fully understood yet. The decrease in cerebral grey matter (GM) volume may be due to a neuronal pruning reducing their number, and/or a dendritic connections expansion that brings neuron cell bodies closer, precisely and mainly located in the GM networks supporting the motherhood emergence. Moreover, lots of the structures described by Preckel K *et al.* (28) in ToM, compassion and empathy networks are common with the both versions of maternal caregiving behavior brain circuitry of Gholampour F *et al.* (11) and Shimon-Raz O *et al.* (29), leaving strongly assumed that these qualities are the basis of motherhood *(figure 10).*

This overview aimed to identify the cerebral anatomy's modifications appearing in women during pregnancy or in postpartum. Secondly, this study seeked to show when these adaptations appear and for how long time, and what impacts they have on mothers' general cognitive functions and towards newborn babies.

METHOD

Research strategy

This systematic literature overview was conducted under the PRISMA 2020 flow diagram model for original systematic reviews, including searches of databases, registers and other sources (30). The following databases, NCBI, PLOS, Ulysse, Google Scholar, Cochrane Library, CAIRN and BDSP were used with chosen keywords to define two main concepts : 1) "neuronal plasticity", "brain", and 2) "pregnancy", "postpartum". A third concept was introduced 3) "maternal behavior" or "motherhood" to meet a secondary objective *(see table 1).* This review has been made between July the 15th, 2020 and July the 8th, 2021.

Table 1: Keywords used to identify articles on the corresponding databases

Databases	Keywords
NCBI	("maternal brain" OR "neuronal plasticity") AND (pregnancy OR postpartum) AND "maternal behavior" NOT rat[Title] NOT mouse[Title] NOT rats[Title] NOT mice[Title]
PLOS	"neuronal plasticity" or "maternal brain" and pregnancy or postpartum and "maternal behavior" or motherhood

Ulysse	neuronal plasticity pregnancy postpartum “maternal behavior” (without rat*s, mouse/mice, stress, depression)
Google Scholar	"neuronal plasticity" AND brain AND pregnancy AND postpartum AND "maternal behaviour" AND motherhood
Cochrane Library	brain pregnancy maternal behavior
CAIRN	brain pregnancy postpartum maternal behavior
BDSP	(brain) AND (pregnancy) AND (maternal behavior)

Eligibility criteria and papers selection

Inclusion criteria for articles eligibility were : 1) no literature review or meta-analysis ; 2) studies on women ; 3) mothers without chronic/gestational diseases or mental illness (like psychosis, anxiety disorder, postpartum depression, maternal burn-out), so without treatment or addiction ; 4) mothers who had physiological pregnancy, childbirth and postpartum periods ; 5) full-texts written in French or in English. First, all papers were screened and selected by title, then by abstract and finally by full-text reading. Duplicates were removed after the abstract selection step because that was simpler to do on our own “manual way”, without software. Other articles were identified by screening bibliographies of selected articles, through authors and available reviews on our subject of interest. The selected studies, finally irrelevant to the primary objective or of poor quality and / or with many biases were excluded.

Studies types and quality assessment

The studies types were determined after the first full-text reading of each paper and all are either cohort studies or cross-sectional studies, controlled or not. So their quality was assessed with the study quality assessment tool for observational cohort and cross-sectional studies of National Institutes of Health. No scale is available with this evaluation method to define whether studies are of good, fair or poor quality, so we have chosen to express it as a percentage of yes on a total of 14 different items. A study with a rate lower than or equal to 50% was considered as of poor quality, between 50,1% and 75% as of fair quality and more than 75% as good quality study. Articles of poor quality were eliminated.

Data extraction and compilation

Data were extracted and compiled in a detailed table *(Table 3 in annexe)* describing for each included study, test and control groups (size, middle age of participants and obstetric history as parity, gestational age), moment(s) of MRI measurement(s), principal objective and secondary objectives and an onset of discussion elements, limits and bias. Another table (*Table 4 in annexe*) summarizes the results.

RESULTS

OBTAINING ARTICLES FOR THE REVIEW

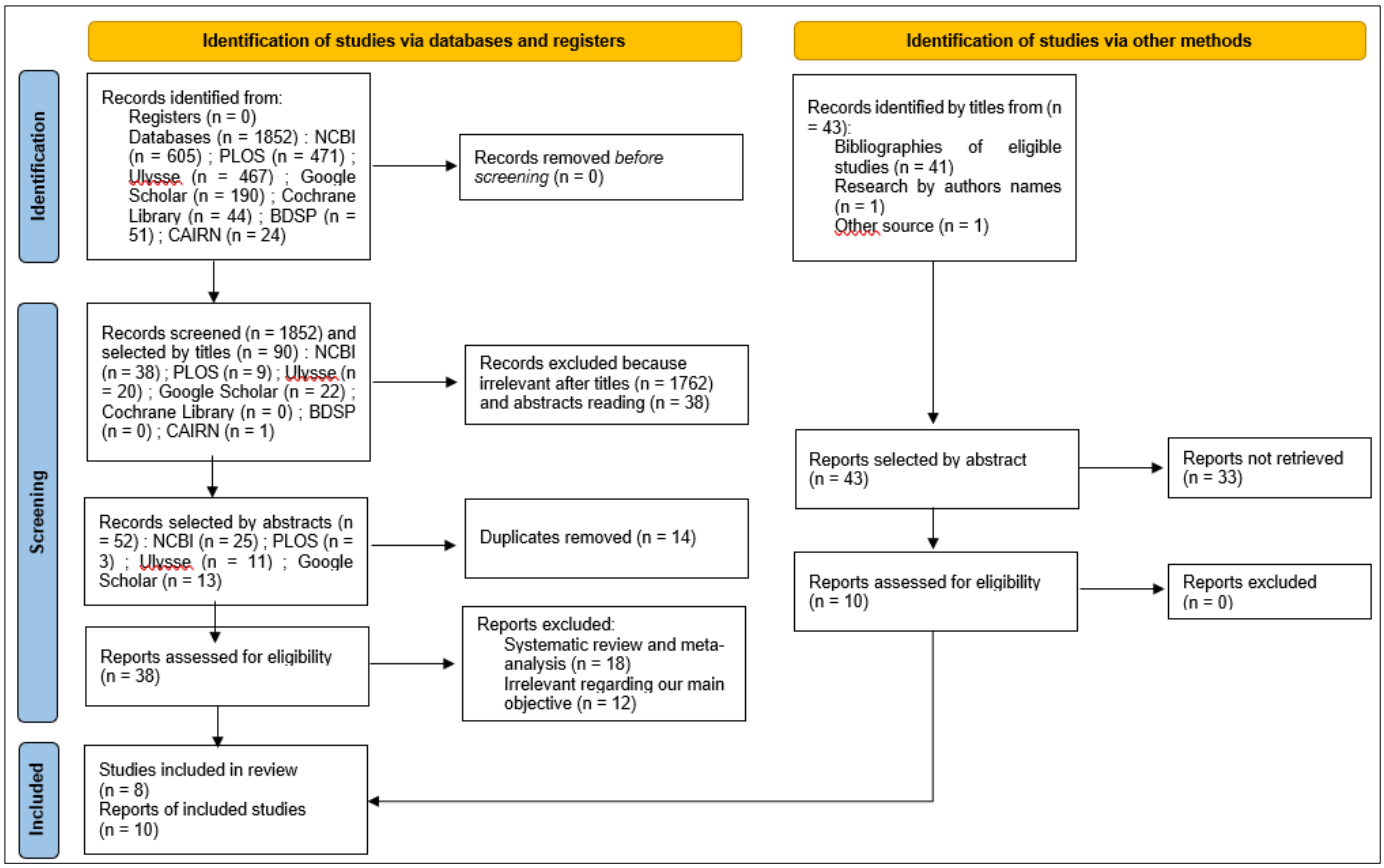

Figure 1: Literature review flow diagram according to PRISMA 2020 model (30).

Studies selection

A total of 90 of all 1852 papers identified by databases were selected by their title and 38 were eliminated by abstract reading. After 14 duplicates' removal, 38 articles were eligible for the review and eight were finally included. All bibliographies of these papers were analyzed to find more interesting articles, and 41 abstracts were read after selection of these studies by their titles. Thereby, eight more articles were included, and their bibliographies were studied too, without finding any other item to include. More papers were researched by the first author's name of the primary included studies, which led to finding one more article. While looking for references to support our discussion, we found an article by chance that can also be included in our review. Finally, eighteen studies were included in this systematic review (*Figure 1).*

Studies types and quality assessment

Two types of study were found among the included articles : cross-sectional (n = 7) and cohort studies (n = 11), either uncontrolled or controlled. The study of Hinshaw DB Jr *et al.* (31) was judged with a poor quality and was excluded, seven studies were of fair quality and ten studies were of good quality level *(Table 2 in annexes).*

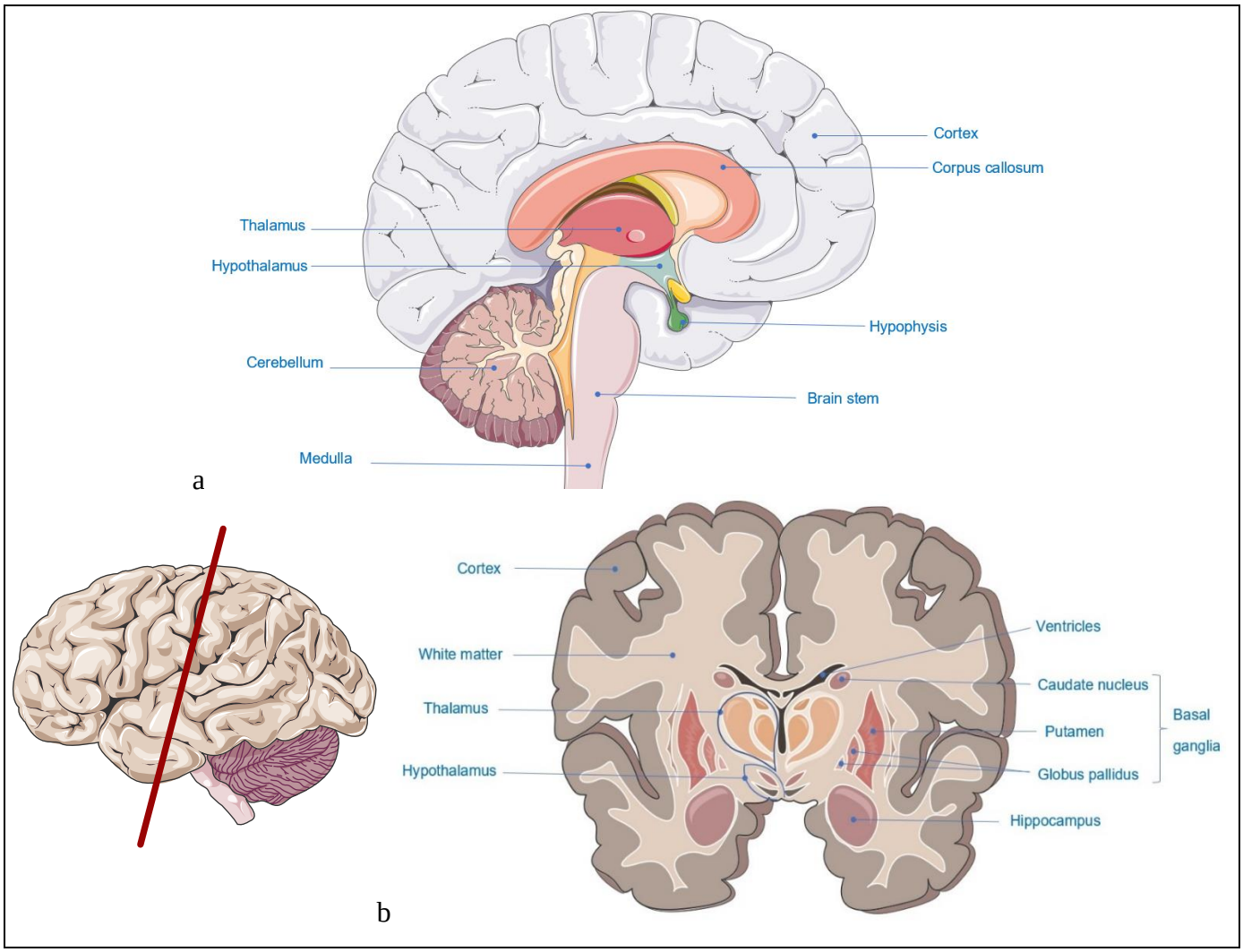

Figure 2: Brain anatomy (adapted from smart.servier.com)

a) brain midsagittal section ; b) brain frontal section going through the central sulcus

REVIEWING OF OBTAINED ARTICLES

Whole-brain volume

Brain is a vital organ housed in skull and whose anatomy is very complex *(Figure 2).*According to Oatridge A *et al.* and Carmona S *et al.*, the global brain volume seems to decrease during pregnancy. Oatridge A *et al.* concluded that a linear diminution of the cerebral volume occurs along the pregnancy (mean of -5,35%, n = 9), then there is a fast increase of this volume at six weeks after birth, with a complete return to normal between five and nine months of child's life. Carmona S *et al.* estimated a reduction of 0,1%/M on a time-lapse of 15,5 ± 3,5 months (n = 25). No conclusion was available about a potential persistence or a regression of lowering beyond two and a half months PP.

Cortical volume (CV) and thickness (CT), gyrification index

Cerebral cortex is the most voluminous part of the brain (⅔ of global volume), constituted of five outer layers of GM (grey matter) and of one sixth inner layer of WM (white matter). Divided in six symmetrical

lobes, it manages the superior cognitive functions like thinking, reasoning or speech. Brain cortex has folded appearance to increase its surface with convolutions named gyri, delimited by furrows called sulci. (33-35)

Five researchers teams looked at the cortex adaptation through gestation (n = 25 for all studies, except n = 9 for Luo H *et al.*) and showed a diminution of CV (26,27,32,36,37) and CT (32) during pregnancy, principally in frontal, parietal and temporal lobes and in cingulate cortex. The mean reduction was of 0,2%/M for CV and of 0,1%/M for CT (time-lapse = 15,5 ± 3,5 months) according to Carmona S *et al.* This decrease seems to persist after birth, two years (27, n = 11) and even until six years in fusiform gyrus, prefrontal cortex, precuneus and superior temporal cortex (37, n = 7).

Kim P *et al.* (n = 19) was the first team to focus more specifically on anatomical variations of brain GM in restricted cortex regions in new mothers. Like other teams after them only interested in cortical changes occurring during the first six PP months, they observed an increasing CV (38, n = 19 ; 39, n = 24 ; 40, n = 14) and an increasing CT (41, n = 39) in certain brain regions like prefrontal and limbic cortices or insular, parietal and temporal lobes. Conclusions about the evolution of CV and CT during PP are diverging. Indeed, Zhang K *et al.* (n = 35) demonstrated a decreasing CV and CT at eight months after birth that persisted up until two years PP, joining the conclusion of Hoekzema E *et al.*, 2017. Orchard ER *et al.* (n = 235) searched if differences were still visible in third age mothers compared to older women who never had children. Their results showed that motherhood leaves diminished CT decades after the last birth in all regions of interest, except in the parahippocampal gyrus where an increased CT is shown.

About gyrification index (ratio between the actual and the exposed cortical surface), Carmona S. *et al.* (n = 25) found a reduction after pregnancy and Zhang K *et al.* (n = 35) showed a rise from eight months then a stabilization at two years after birth.

Cerebellum volume

Cerebellum, situated back to the brainstem under occipital lobes, helps above all to coordination, synchronization and precision of movements and equilibrium in standing and walking but has a cognition function too, in attention, language and emotion regulation (33-35). It have several symmetric lobes like cerebral hemispheres, and like cerebral cortex, it has two outer GM layers and one WM layer.

Included in whole-brain study of Oatridge A *et al.* (n = 9), cerebellum decreases in global volume in prepartum and increases rapidly after birth. Cerebellar GM volume seems to decrease during pregnancy (26, n = 25) and to increase up to five months in PP (38, n = 19 ; 39, n = 24). Zhang K *et al.* showed an increased cerebellar WM volume (n = 35) at one year of PP in comparison with nulliparous women.

Ventricles and white matter (WM) volumes

Ventricles are an internal irrigation system which permits to make float the brain in the skull and to feed it with nutrients of cerebrospinal fluid. WM is the inner and thicker layer of cortex, its color is lighter

because it contains only the axons of neurons whose cell bodies are in the GM layers. Axons form conduction bundles of electrical nerve information, allowing neurons in different parts of the brain to communicate with each other and coordinate their functions. The study of the interactions between brain areas and the activity of this complex network of nerve fibers is grouped under the name of connectome. (33)

Only Oatridge A *et al.* (n = 9) measured ventricles and found an increased volume during pregnancy with a return to normal between the fifth and the ninth PP months. Zhang K *et al.* (n = 35) was the only team to demonstrate a bigger WM volume in PP until two years after birth, mainly in parietal lobes and insula.

Pituitary gland (PG) volume, convexity, and signal intensity

PG (or hypophysis) is located below and before hypothalamus and has a very important endocrinologic function, notably in childbirth and breastfeeding. Prolactin is produced and released by the lactotroph cells of anterior hypophysis lobe (also called adenohypophysis) for milk synthesis, only this lobe has a real glandular function. Oxytocin is released by posterior hypophysis lobe, also named neurohypophysis, this lobe actually has only a secretory function. (33-35)

PG increases in volume (44, n = 32 ; 25, n = 9 ; 26 n = 25) and in convexity (44) during pregnancy. After birth, its volume decreases with a return to normal toward eight (25) or nine months of PP (45, n = 12). Miki Y *et al.* showed a diminution of adenohypophysis signal in intensity and in convexity after birth in lactating mothers with a normality recovery, respectively between four and eight months, and between eight and twelve months, and no change in neurohypophysis intensity in PP. After a year, this study didn't demonstrate any difference in PG volume, convexity or adenohypophysis signal intensity between women who were still breastfeeding and those who had weaned their babies.

Limbic system volume (hippocampus, amygdala, fornix and mamillary bodies except limbic lobe)

Limbic system is a set of even structures situated in deep cerebral hemispheres and implicated in instinct, survival and emotions, in particular by integrating dangerous events into memory. Hippocampus has a major role in spatial orientation and in short and long-term memory and learning, and hippocampal damages can be found in neurodegenerative diseases like in Alzheimer. Amygdala allows the recognition of dangerous situations, management and reaction to stress and fear ("fight or flight" response). Mamillary bodies also have a memory and an alertness function. Fornix is a sheath containing the nerve fibers that connect mamillary bodies and hippocampus together. Olfactory bulbs and nerves relay sense of smell informations, are parts of limbic system too but, because of theirs great regression during the human species evolution, there are only very little studied compared to animals, while they certainly have an important role in the constitution of emotional memory. (33-35)

Barba-Müller E, 2015 (n = 25) and Hoekzema E *et al.*, 2017 (n = 25) found a decrease in hippocampus volume during pregnancy. Moses-Kolko EL *et al.* (n = 137) showed that this diminution is visible too at

four months of PP, while Lisofsky N *et al.*, 2016 (n = 30) did not find any difference during the two first months PP. It seems that an increase occurs until at least the second year after birth (27). Kim P. *et al.,* 2010 (n = 19) found a volume increase in the mammillary body and amygdala during PP. Moses-Kolko EL *et al.* (n = 137) found a not significant increased volume in amygdala too.

Thalamus and hypothalamus volumes

Thalamus, the most central brain structure, is a grouping of more twenty nuclei pairs called thalamic bodies and has the role of functional crossroads for sensitive messages (except smell) and motor responses between spinal cord and cerebral cortex. It is also in charge of directing emotional stimuli to the correct areas. Hypothalamus, located under thalamus, is a grouping of more twelve symmetric sets of ganglia forming a link between the nervous and endocrine systems by producing hormones which regulate other hormones' synthesis by endocrine glands such as hypophysis, thyroid, ovaries. For example, oxytocin is produced by paraventricular and supraoptic nuclei of hypothalamus, routed via neurosecretory cell axons of pituitary stalk and liberated by posthypophysis in blood circulation for labor uterine contractions during parturition and for milk ejection. It has a role in emotions and instincts via connections with limbic system (33-35).

No results are available concerning thalamus and hypothalamus anatomical adaptations during pregnancy. In PP, Kim P *et al.,* 2010 (n = 19) and Luders E *et al.,* 2020 (n = 14) showed that birth is immediately followed by a rise of thalamic and hypothalamic GM volumes till four months PP. Zhang K *et al.,* 2020 (n = 35) didn't find difference in thalamus volume at eight months PP but showed a lowering of thalamic GM volume at two years after birth.

Basal ganglia (BG) or nuclei volumes

BG are several pairs of GM zones located in brain center connected with most of other brain parts., first including the subthalamic nuclei and substantia nigra under thalamus, then, next to thalamus from inside to outside, globus pallidus (internal and external GP) and putamen, and finally caudate nuclei, forming a sort of comma going backwards whose the head is located above thalamus and the tail is between external GP and hippocampus. Other nuclei names could be saw in books and studies but these are in fact the names of BG groupings like lentiform (putamen + GP), dorsal striatum (putamen + caudate nucleus) or corpus striatum (putamen + caudate nucleus + GP). Others still are less important in size and are therefore less studied like claustrum, implicated in consciousness, between putamen and insula or like accumbens nucleus, which plays a role in the pathway of reward and addiction, placebo effect and certain emotions, at the tip of dorsal striatum and forms with the olfactory tubercle, the ventral striatum. (33). All major BG are interconnected and have a multitude of functions but mainly in motor control with planning, initiation and coordination of movements to make them fluid and coherent, in relation with cortex, cerebellum and thalamus.

Hoekzema E *et al.*, 2020 (n = 20) found a decreased volume of ventral striatum after pregnancy, which persists two years after birth. Lisofsky N *et al.*, 2016 (n = 30) proved a diminished striatal volume during the two first months PP. Similarly, Zhang K. *et al.* (n = 35) found a decreasing GM volume in putamen, lentiform nucleus, globus pallidus (GP) and claustrum associated with an increasing WM volume in the same BG except GP at one year PP, and a diminished caudate nucleus two years after birth. However, three studies reported an increase in different BG volumes : in substantia nigra, caudate, putamen and GP till fourth months after birth (38, n = 19) ; in accumbens nucleus as of first to fifth months of PP (39, n = 24) ; and caudate until the sixth month of baby's life (40, n = 14).

Brainstem and medulla GM volume

Brainstem, regrouping the mesencephalon, the pons and the medulla oblongata, is the big crossroad joining hemispheres, cerebellum and medulla together, from there are born most pairs of cranial nerves, and is mobilized in automatic movements, the subconsciousness and in unfocused diffuse mental activities like thinking or remembering. The upper medulla (with medulla oblongata) contains some parasympathetic autonomic nervous system nuclei which regulate, among others, the respiratory and circulatory functions.

Kim P *et al.*, 2010 (n = 19) were the only study to look at changes occurring in brainstem, showing a decrease in GM of pons and medulla.

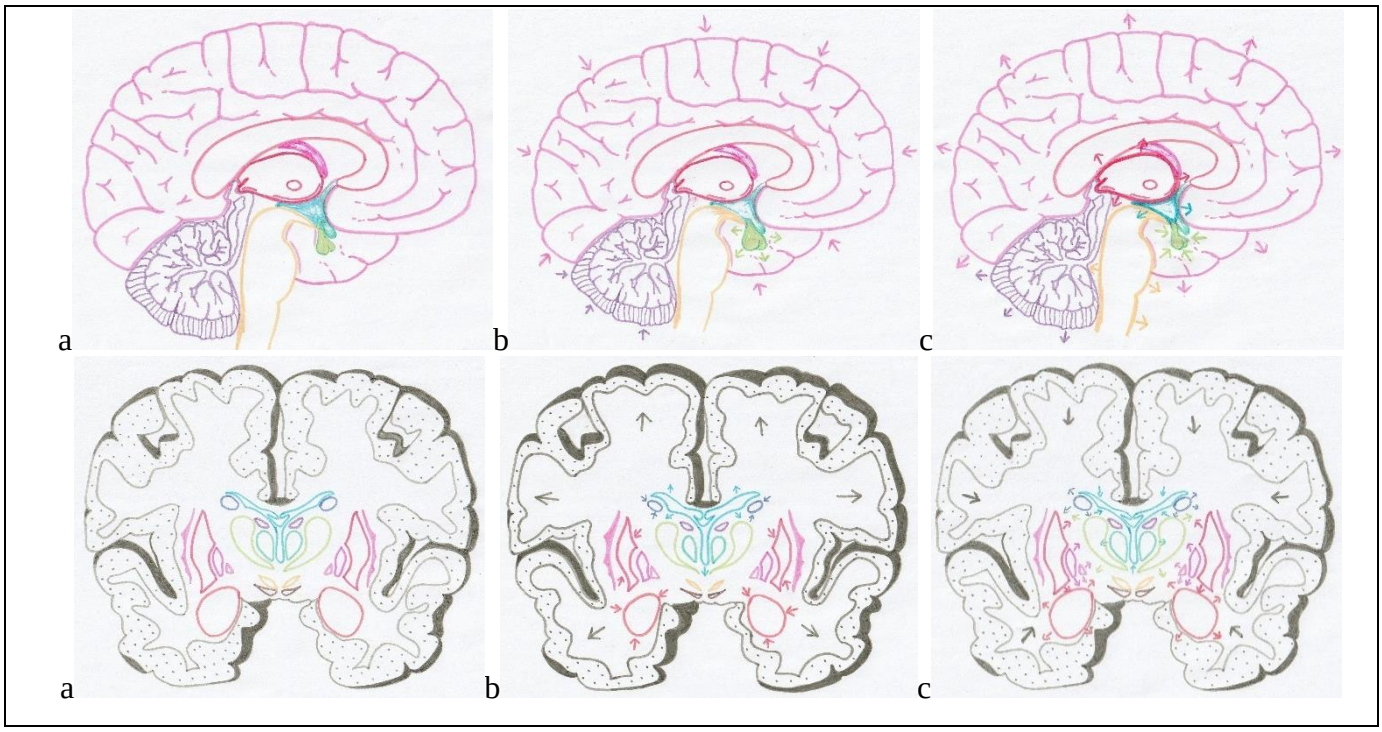

Figure 3 : Schemas of volume variations of maternal brain structures before (a), during (b) and after (c) pregnancy (adapted from smart.servier.com).

The figure 3 summarizes the brain structures' volume variations appearing during pregnancy and after birth.

Enrolled cortex zones

The GM decrease don't appear uniformly over the entire cortex. The diminished clusters were identified in specific cortex zones known as supporting important cognitive functions like social interaction, memory, emotion and stress gestion, which are playing a role in maternal behavior (47). The ToM and DMN brain circuits were also identified as activated in the same brain regions where GM cortices shrink in mothers (26,27,47). Last, the reward circuit has an important implication in maternal motivation and caregiving (47). The frontal lobe (managing affective functions, motivation and decision making for orbitofrontal cortex (OFC), and thinking, planning, memory and social interactions for upper prefrontal cortex (dorsoPFC) (49)) seems to be the most impacted brain lobe by pregnancy (mentioned 65 times in all studies). In second position, we have the parietal (which participates in integration of sensorial messages, in spatial organization and attention), temporal (implicated in shape and objects recognition, generation and storage of memories and in language) and limbic (cortical part of the limbic system, permits long-term memory storage, notably about decision making and reactions to stressful situations) lobes, respectively mentioned 38, 37 and 33 times in all articles. Third, the insula (quoted 17 times) is used for internal sensations and own body representation called interoception ; and for conscious experiences of our emotion and feelings. Other structures like caudate and accumbens nuclei, cerebellum, amygdala and occipital lobe (implicated in vision) are less impacted by change (cited 10 times or less) but are equally important in motherhood (*Figure 4 and table 5)* (33,35).

None of the studies in the review can explain the mechanisms leading to this decrease in GM, but neuronal pruning with loss of matter or neurons expansion with increased proximity of cell bodies were two hypotheses issued by Hoekzema E. *et al*., 2017. Nearly all studies showed an asymmetrical appearance of cerebral adaptations between the right and left brain hemispheres, but for each impacted structure the dominant side is different from one article to another. Finally, there is no significant trend in favor of one side over the other if we look all works globally (*Figure 4).*

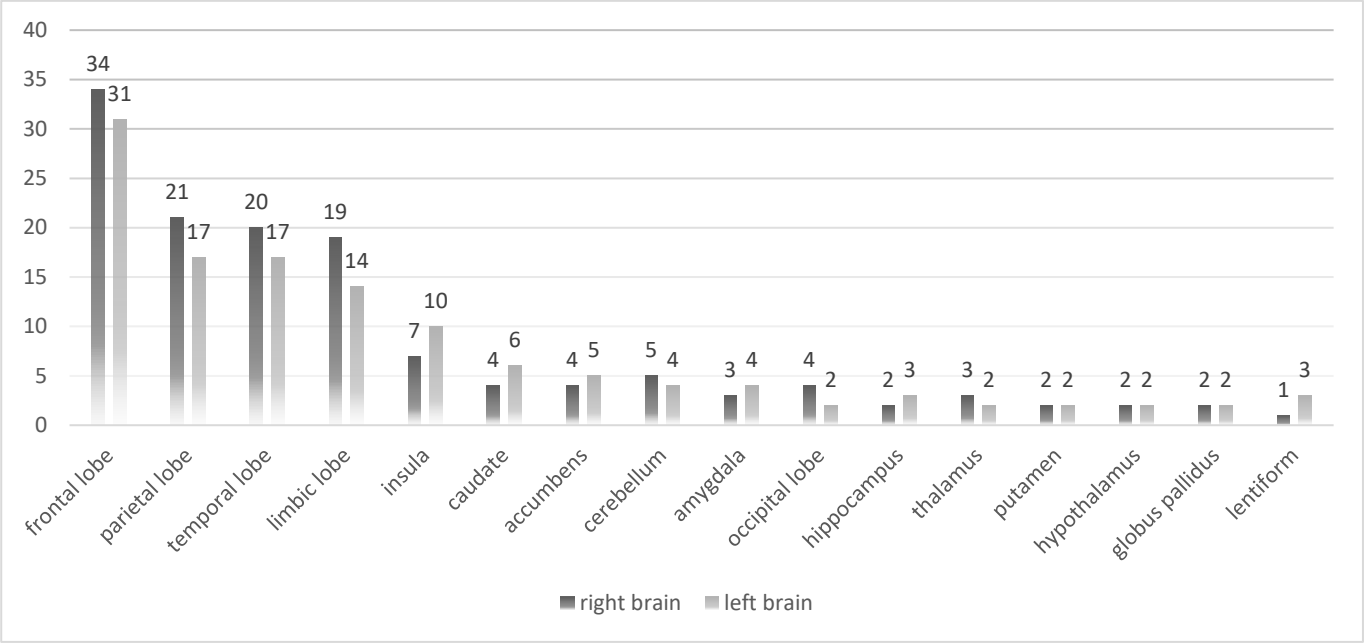

Figure 4 : Structures impacted by pregnancy and the number of times when they were quoted in papers. Structures quoted less than four times for both hemispheres were not listed.

If we consider only cortex, the ten gyri more susceptible to be impacted by pregnancy than others (*Figure 5*), are at first the middle and superior frontal gyri (quoted 18 and 15 times) ; then the cingulate, inferior frontal gyri and insula (cited 12, 11 and 11 times) ; thirdly the precentral, the precuneus and the parahippocampal gyrus (8 times all three) ; and finally the orbitofrontal and inferior parietal gyri (6 times both). Others structures were found 5 (middle occipital and superior temporal gyri) or 4 times (postcentral, inferior occipital, middle temporal and fusiform gyri) to be activated by maternal behaviors according to our review. The other gyri are less affected by adaptations (found quoted three times or less in all studies). Only a few papers used additional Brodmann areas (BA) precision and the five ones the most quoted in studies are BA 6 and 8 which correspond to premotor cortex, BA 9 and 10 which represent the dorsomedial and ventromedial PFC (dmPFC and vmPFC) and BA 13 which is insula. *(Figure 6)*

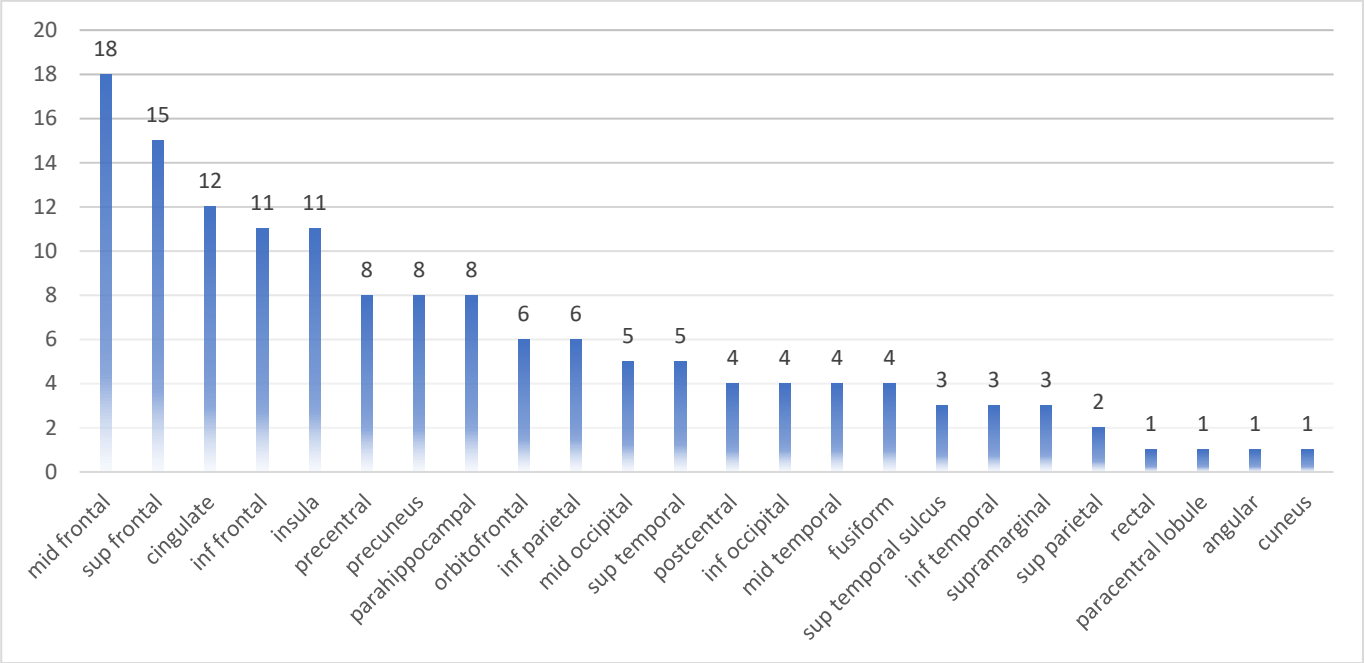

Figure 5 : The main cortical gyri and number of times they have been found to be impacted by pregnancy.

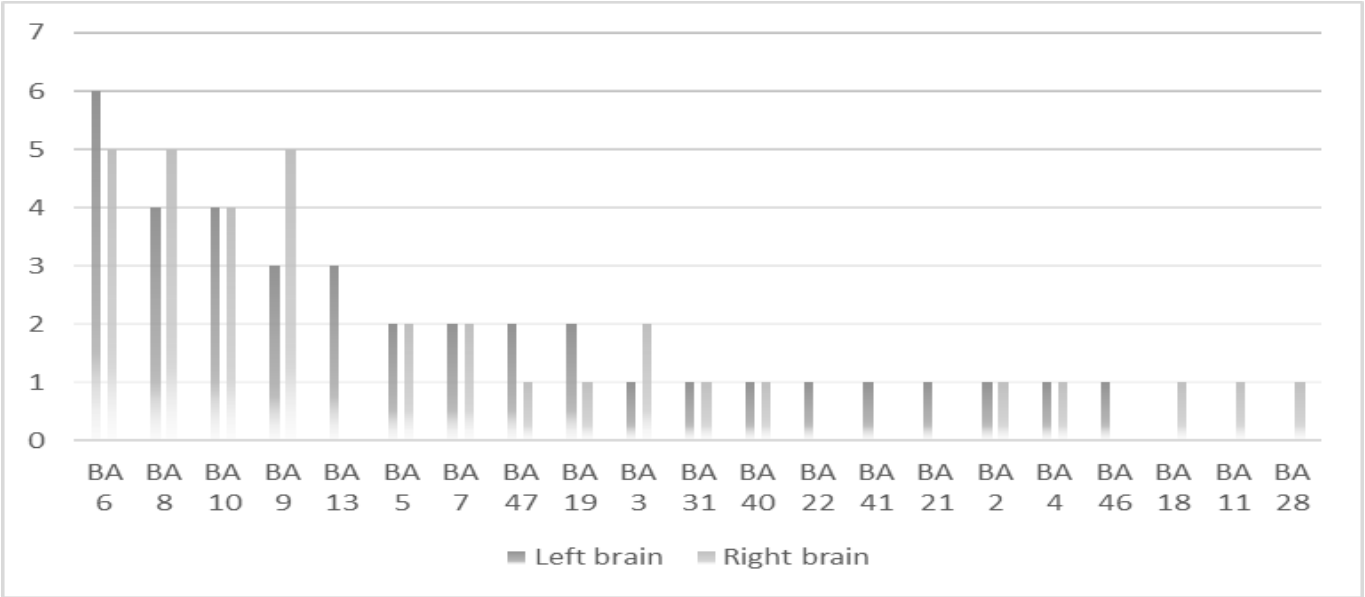

Figure 6 : The Brodmann areas (BA) and the number of times they have been found to be impacted by pregnancy.

Impact on cognitive abilities, social qualities, and maternal skills

Different studies shows no difference in cognitive performances (26,27,39), while others describe a decrease in navigation abilities and difficulties in learning route (48) or best memory capacities in multiparous mothers compared to nulli and primiparous women at short and long terms (37,43). More empathy was observed in mothers compared to nulliparous, with better listening capacities and ease to understand other people's emotions and feelings (42,47) whereas Barba-Müller E, 2015 didn't see any difference in empathy according to the tests carried out.

Almost half of the studies have shown either a positive effect on maternal motivation and effectiveness felt in mothering care, and a good perception of mother-infant relationship and attachment, in correlation with the importance of brain modifications (27,37,38,41,46) ; or a high sensitivity to baby cries and cues and an ease to decode and respond to them for better mother-child interaction and caregiving. (26,27,40,42,43)

DISCUSSION

Principal findings

This systematic review of literature permitted us to partially meet our principal objective in highlighting the anatomical adaptations of maternal brain in expecting women but this question was not completely answer about what happens in new mothers. Indeed, concerning the prepartum period, studies found a progressive diminution of global cerebral and cortical GM volumes mainly in frontal (notably in PFC, OFC, premotor and primary motor cortex (PMC)), parietal (postcentral, precuneus, lateral parietal cortex), temporal (superior gyrus, temporoparietal junction, fusiform), limbic (mainly cingulate gyrus), insulate lobes and of cerebellar and basal GM volumes, with a minimal volume reached around the birth. On the other hand, the conclusions diverge about what happens after birth for the direction of variations and the persistence of adaptations. Some researchers teams found a reset of brain modifications rapidly after delivery when others established that certain adaptations continue during several months, or even years, after baby birth. Furthermore, pregnancy and childbirth leave indelible marks on women's brains even at elder age. Concerning the intellectual consequences like on memory or empathy, studies results have some discrepancies but for maternal behaviors and skills, many teams agree to say that mothers succeed easily to understand babies' cries and can adopt a behavior adapted to their needs.

Discrepancies in results

The differences in the PP adaptations conclusions in articles seem to come from the different ways the studies were conducted. The presence or absence of a control group, the number of participants, the time and repetitions of the measures before, during and/or after pregnancy, the equipment and softwares used for measurements, the radiologists competence and performance, so many parameters involved in obtaining and analyzing the results that can explain these discrepancies.

Given the different methods used in the articles analyzed in the review, the ideal study to conclude would be a cohort study with a large number of participants including several test groups with women of gradual level of parity (primi, secondi and multiparous), controlled by age-matched groups of nulliparous under continuous hormonal contraception to avoid brain fluctuations during menstrual cycle (50) or between D0 and D7 of their menstrual cycle which is time of the cycle with the lowest hormone rate. The method would be based on a MRI follow-up before pregnancy, then at least once per trimester during pregnancy (maybe at same moment than recommended fetal ultrasounds), one measure around birth and finally several regular

measurements during a few years of PP, closer first then further apart. Blindly MRI could be carry out by at least two very experimented radiologists, who wouldn't know if women are in test or control groups and at which moment of gestation or postpartum they are, to avoid measure bias.

Limits and bias of the recruited articles

Even if all studies of our corpus are prospective, the principal limit of this overview is the weak scientific proof level of cross-sectional studies (level 4 from HAS), whether they are controlled or not, which represent the almost half of all papers included in our review (n = 7). The rest of the articles (n = 10) are cohort study with scientific presumption (scientific proof level 2 from HAS). In the field of obstetrics, it is ethically and technically difficult to conduct randomized, double-blind, comparative studies on pregnancy physiology, hence the low power of the articles found on the subject.

We can evoke another limit to our review which is that several articles are actually continuation of others and so really represents only one study with the same patients but with results that extend over several years (26,27,37) and others articles are further studies of the first (32,47), giving the impression that is a very studied topic when in reality there is very little expert team on this theme of study and thus multiplying their prepartum results by five also while their control and test groups are basically made up of the same subjects.

Difficulties to finding studies during pregnancy in healthy women

Studies about maternal brain abound, especially on cognitive and psychiatric aspects, but studies on maternal brain anatomy of healthy women were rare until 2015. First studies were conducted on deceased pregnant women and more or less young mothers on the occasion of autopsies. Except by imagery methods, it's impossible to study brain anatomy on alive women, and these methods require advanced technologies in nuclear magnetic resonance. Only two studies of this review shows brain modifications really during pregnancy (25,44), whereas the others shows these modifications after pregnancy in comparison with ante-conceptional state. This can be explained by the ethically questionable aspect of passing pregnant women repeatedly through an MRI machine for scientific and no diagnostic goals, even if this is a priori harmless for the fetus whatever the term of pregnancy according to the CRAT (Centre de Référence sur les Agents Tératogènes).

Way to express results and interpretation difficulties

We have noticed that the authors do not express their results in the same way for the localization of brain modifications. Some use the denomination in gyri, others in cortices, sometimes we find the two denominations considered as synonyms, certain specify these denominations using the Brodmann areas (BA) parcellation. These many ways of naming the GM regions have different levels of precision in location and functionality, and make the interpretation of the results complicated. The gyrus denomination permits to only describe the superficial anatomy of brain, without the functional aspect of the areas and with an

average accuracy because of large variety of gyri size. For the biggest gyri, the authors have to make clear with terms like “anterior”, “middle” or “posterior” but there is no consensus on the limits between the different parts. The term cortex rather designates an executive area of higher cognitive functions that cannot be delimited with the naked eye, cortex appellation has more interest thanks to the notion of cognitive roles but its precision is debatable because the boundaries are not consensual from one writing to another and few cortices, like PFC, are so big that it is necessary to subdivided them in littler ones, themselves sometimes subdivided littlest. Some gyri and cortices are overlapping each other’s like orbitofrontal one, but sometimes a same gyrus contains several cortices or certain cortex covers several parts of different gyri. Another way to express results is the BA denomination which is the most precise denomination, while their number and delimitations have evolved over the century (*see figures 7 to 10 and table 5 to have examples*). These specificities make it all the more difficult to interpret cerebral adaptations

Relation between brain structures impacted during pregnancy and maternal behaviors

The maternal caregiving network structures shrinked by pregnancy are implicated in many various brain function circuits like planning, movement, language or emotion but what are their links with maternal behavior. The primary needs of a newborn are not very numerous (to eat, to sleep, to relieve her/himself, to have a clean diaper and to be cuddled) but the absence of elaborate language makes very difficult to interpret the cues that she/he send. A mother must be able to understand and recognize them through crying and facial expressions or by proceeding by elimination, and provide an appropriate response, such as feeding her/him if she/he is hungry. To take care of others is based on several social cognitive abilities involving the emotional brain : empathy is emotions and feelings (good or bad) recognizing and sharing process, compassion is felt in the face of someone's suffering and can provoke a behavior of solidarity. Empathy and compassion are often confounded, especially when trying to comfort someone who is crying for example. Theory of Mind (ToM) is another social awareness promoted during late pregnancy and PP which allows us to deduce the state of mind of someone else thanks to our analysis of their attitude or emotional expressions. (33,51) Numerous structures implicated in these cognitive functions are common with the maternal caregiving networks of Gholampour F *et al*. and Shimon-Raz O *et al*., showing that these social skills are important and promoted when a woman becoming a mother for an easier recognition and deduction of newborn emotions and needs with a right reaction in taking the good decisions to respond to the baby cues. Memory and language are very important too because they permit to perceive the tiny variations in crying and to have faster reaction in the face of expressed cues. Emotion involves a large majority of these structures which may indicate that it guides most of our major cognitive functions and the way we react to others, we are sociable beings endowed with feelings above all. (11,29,33) *(see table 5)*

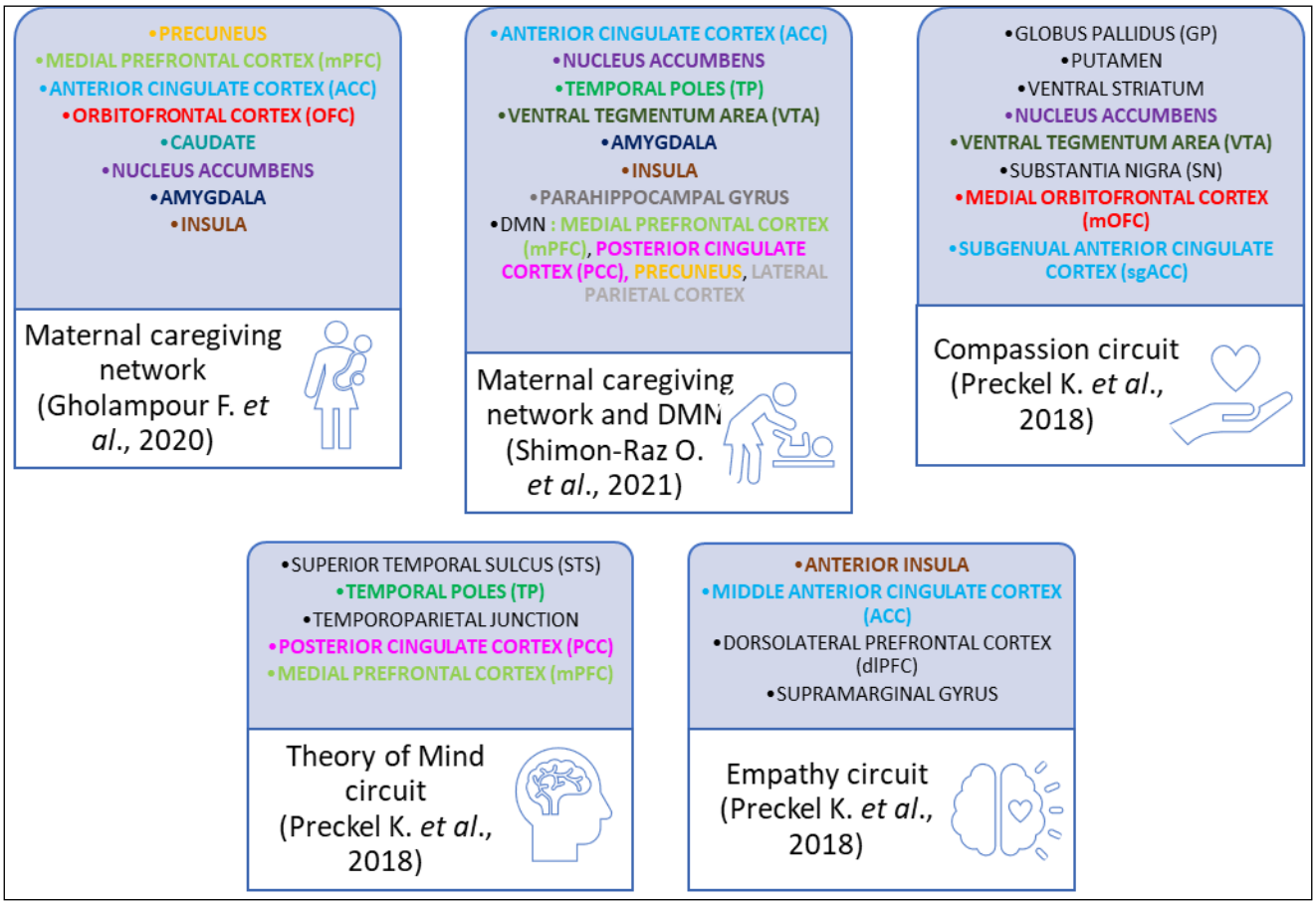

Figure 11 : Schema of maternal caregiving brain networks according to Gholampour F et al. and Shimon-Raz O et al. compared with ToM, compassion and empathy circuits of Preckel K et al. Common structures between the different networks were marked by similar colors which were used to marked them in table 3 too. Structures composing the DMN according to Raichle ME are detailed below the DMN puce of Shimon-Raz O et al.'s frame.

Table 5 : The different cortices (corresponding BA) and brain structures implicated in maternal behaviors according to Gholampour F *et al*. and Shimon-Raz O *et al*. (in colors), plus the cortices found to be often active in our review (in black) and their implications in other cerebral circuits and functions. (33) Highlighting colors corresponding to figure 11 and tables 3 and 5 key

Precuneus (BA 7/31)	DMN, attention, consciousness
Lateral parietal cortex (BA 7/39/40)	DMN, morality, memory, movement, decision making
mPFC constitutes by **vmPFC** (BA 12/25) and **dmPFC** (BA 9/10)	ToM, emotion, reward, DMN, morality, altruism, memory, attention, belief, consciousness, social awareness, decision making
OFC (BA 11/47)	Compassion, emotion, reward, altruism, body language, consciousness
Insula (BA 13)	Empathy, emotion, belief
ACC (BA 24/32/33)	Compassion, empathy, emotion, belief, consciousness, stress, social awareness, "eureka moments"
PCC (BA 23/26/29/30)	DMN, emotion, consciousness

Parahippocampal gyrus (BA 27/28/34/35/36)	Emotion, memory, recognition, consciousness, stress, decision making
Temporal poles (TP) (BA 38)	ToM, morality, language
Nucleus accumbens	Compassion, reward, altruism, social awareness
Amygdala	Emotion, morality, body language, memory, learning, stress, social awareness
Ventral tegmentum area (VTA)	Compassion, reward
Caudate	Memory, learning, stress
Primary motor cortex (PMC) (BA 4)	Movement, reaction, mirroring, memory, social awareness, consciousness
Middle and superior temporal gyrus including **STS** and **auditory area** (BA 21/22/41/42)	ToM, emotion, morality, body language, language, memory, learning, social awareness, consciousness, "eureka moments"
Temporoparietal junction (TPJ) (BA 39, Wernicke's area)	ToM, empathy, language, consciousness
Premotor cortex including **supplementary motor cortex (SMA)** (BA 6/8)	Movement, mirroring, emotion, social awareness, consciousness, decision making
Postcentral gyrus (= primary somatosensory cortex) (BA 1/2/3/5)	Movement, memory
Fusiform gyrus (BA 20)	Emotion, memory, social awareness, consciousness, recognition
lPFC constitutes by **vlPFC** (BA 44/45, Broca's area) and **dlPFC** (BA 9/46)	Empathy, emotion, morality, memory, language, attention, consciousness, mirroring, recognition, decision making
Inferior and middle occipital gyri (= primary visual cortex) (BA 17/18)	Emotion, reaction, learning, recognition
Cerebellum	Movement, coordination, balance, attention, language, emotion

N.B. : The lateral parietal cortex includes the superior parietal lobule (inferior and superior parietal gyri) and the inferior parietal lobule (supramarginal and angular gyri), excluding postcentral parietal gyrus (53). The TPJ is constitute of the inferior parietal lobule and rostral end of superior temporal gyrus (54)

Subsidiary questions without answer

Current studies on women don't allow us to understand the underlying cellular mechanisms of the anatomic brain reshuffles. For this, immunohistochemical analyzes should be carried out on cerebral sections from pregnant women/new mothers, a priori in good psychological and psychiatric health, who died of sudden causes, whether or not related to pregnancy or birth (car accident, delivery hemorrhage for

example) but this seems difficult to ethically accept, especially for widowers. If the comparison can be made, animal model experiments have been conducted and have partially explained the processes involved in brain adaptations during gestation after sacrifice and dissection (55-58).

No change was observed in pineal gland anatomy or volume in our review, while melatonin, secreted by epiphysis, presents two inflations, one at the end of first trimester, the second two times higher than the first at the end of the third trimester. Nowadays, only endocrinologic adaptation of pineal gland during pregnancy in women were reviewed, showing disruption of circadian rhythm with insomnia and fatigue. (59,60)

Right and left brains really not equal ?

However, we now know that the two brain hemispheres have a different way of performing the same function although they are anatomically symmetrical : the right brain is more creative, sensitive and emotional while the left brain is more logical, analytical and calculating. For language for example, the left will define the proper meaning of the words in a conversation, the right will interpret the intonation and the emotions conveyed in the speech. There is still a neuromythe in mind that right-handed people have their left brain predominant while left-handed people mainly use their right brain. This belief stems from the fact that there is a reversal of control between the motor areas of the brain and the spinal cord, when an injury reaches one side of the brain, motor skills on the opposite side are affected. Although there may be a slight dominance, we are not totally lateralized, each normally constituted persons use the both halves of their brain to different degrees according to their personality and education, being left or right handed is not related to (33,35). All the same, it seems relevant to seek if having left or right brain predominance impacts cerebral adaptations during pregnancy or mothers behaviors after birth.

Interest of these findings in midwifery practice and skills

Because of the cognitive mechanisms operating during gestation, are pregnant women less able to understand all the advice that midwives can give to them ? One necessary skill of health providers is the ability to adopt language understandable to the general public by popularizing medical vocabulary. This ability should be applied more extensively with pregnant women, to use simple but accurate words and to repeat same things several times to maximize the chances of assimilation. We can deduce the importance to combine oral and written means to address recommendations during antenatal consultations, as well as to use an audiovisual support, mannequins or resin models to explain the progress of childbirth, to target and stimulate all types of memory. The corporal approach also makes it possible, for example, to make women aware of their new expectant bodies, to illustrate the positions to be taken to help the birth or the breathing techniques to prepare delivery by mobilizing the body memory. (33)

The psychological aspect of the cerebral adaptations of pregnancy must pay attention to the major risk of perinatal depression, especially if a history of depressive disorders before pregnancy is known. Perinatal depression affects approximatively one new mother on five and can generate infantile negligence or maltreatment, child homicide ; or maternal suicide, becoming so the first cause of maternal death (61). This period of emotional fragility makes it a critical time for the onset or exacerbation of domestic violence too, with severe obstetric consequences like miscarriages, *in utero* fetal distresses or deaths, premature rupture of membranes, (threats of) premature births, placental abruptions, retroplacental hematomas, uterine ruptures. Many other non-obstetric repercussions are to be feared as maternal isolation, mental/physical/sexual abuse, prostitution, murder in addition to risks to the baby. This intimate partner violence is a supplementary risk factor of perinatal depression appearance with all its sequelae mentioned above. (62) According to a study of INSERM (Institut National de la Santé et de la Recherche Médicale), in France, nearly 2% of women suffer at least once of physical abuse during pregnancy. (63)

Pregnancy and postpartum are so privileged moments to identify and take charge of these two public health problems. The Haute Autorité de Santé has published good practice recommendations for medical professionals to facilitate the overall care of mothers and children. Midwives are the first medical resort at the service of women in terms of reproductive health and are so the most capable to enforce these recommendations for a global and optimal care of women at this particular moment of their lives. (64,65)

CONCLUSION

The whole expecting woman body is adapting to pregnancy, even the brain, from the endocrinological and psychological points of view but also anatomically. (66) We still often hear about maternal instinct, mothers have an innate adapted caregiving behavior towards their offspring. This review allows us to modulate this truth, indeed the neuronal plasticity operating during pregnancy allows young mothers to be more attentive to the needs of their babies and more effective in making good decisions in caregiving. Young mothers sometimes feel really helpless in the face of their little one's crying at risk of developing postpartum depression, so benevolent accompaniment in gestures and empathetic listening by perinatal professionals is essential to strengthen the self-confidence and autonomy of patients although this is not always enough. (10,65)

It would be interesting to know what could modulate the importance of the modifications and the delays of their appearance, maybe age (teenage mothers), parity, multiple pregnancy (more hormones), gestational age at birth (hormones exposure shorter in case of premature birth), breastfeeding practice and duration (oxytocin and prolactin secretion during more or less longer), pregnancies spacing, which implies a study on a very large scale. Understanding these cerebral adaptations operating during gestation could help us to identify the anatomical predispositions to develop or not a postpartum depression, like women with mental condition or illness. (33)

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ANNEXES

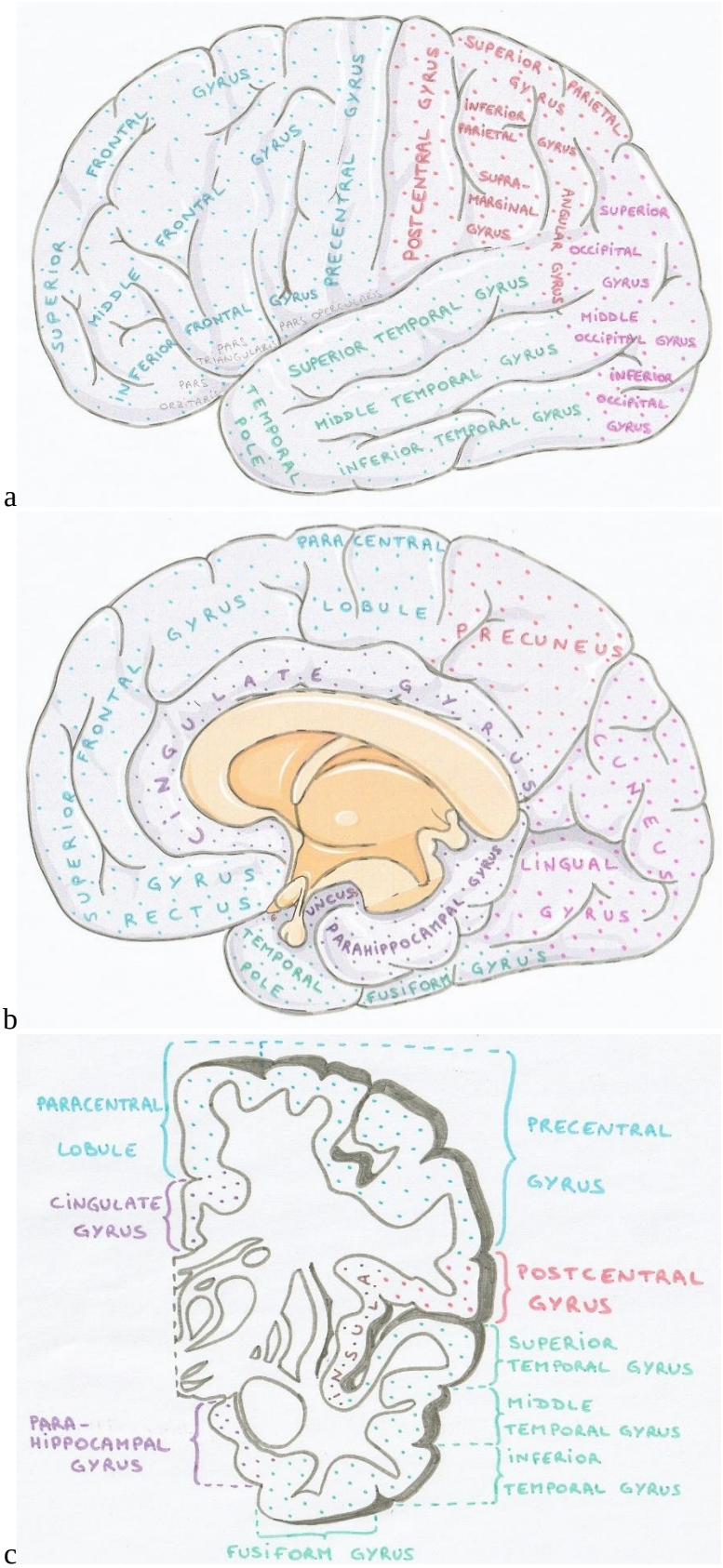

Figure 7 : Gyri names of brain lobes and insula [frontal (blue), parietal (red), occipital (pink), temporal (green), limbic (purple) lobes, insula (brown)]. a) lateral view of the left hemisphere b) medial view of the right hemisphere c) brain frontal section going through the central sulcus (adapted from smart.servier.com).

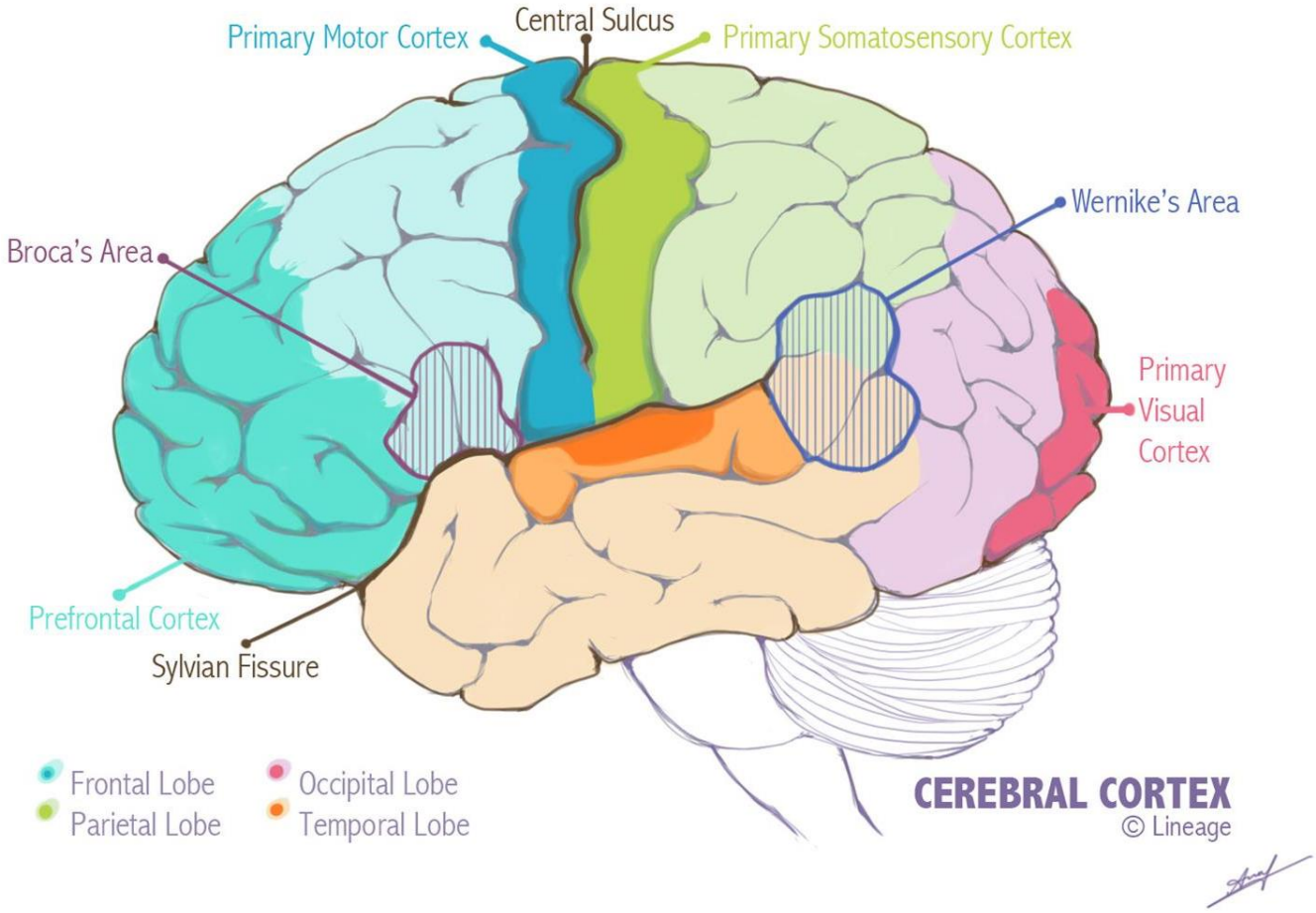

Figure 8 : The different motor and sensory cortices/areas

(from : step1.medbullets.com/neurology/113013/cerebral-cortex)

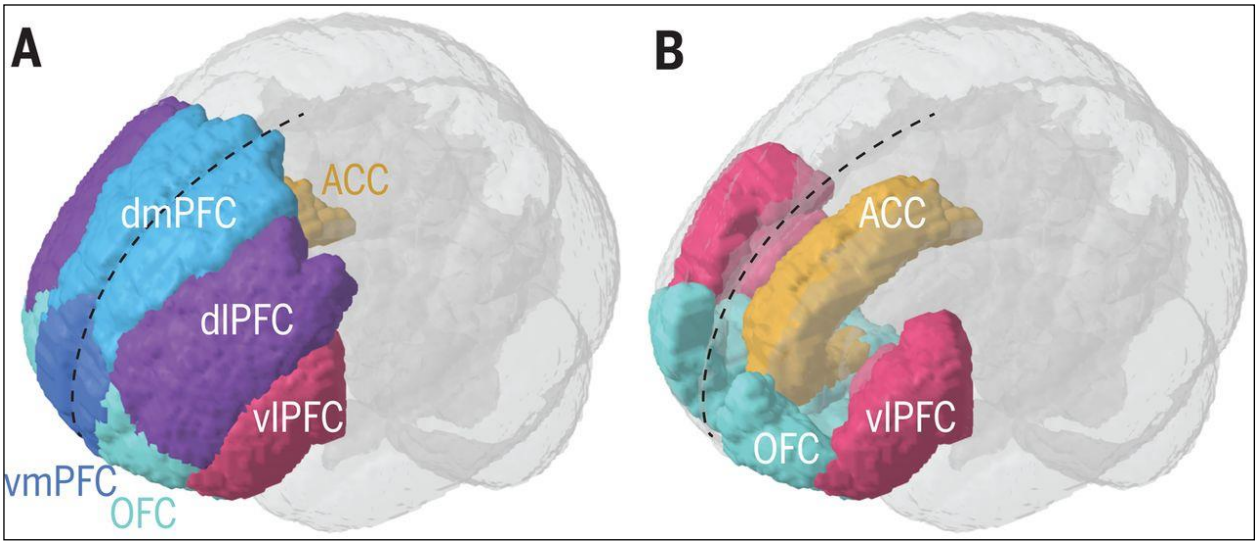

Figure 9 : The PFC subdivisions, OFC and ACC (from Carlèn M., 2017)

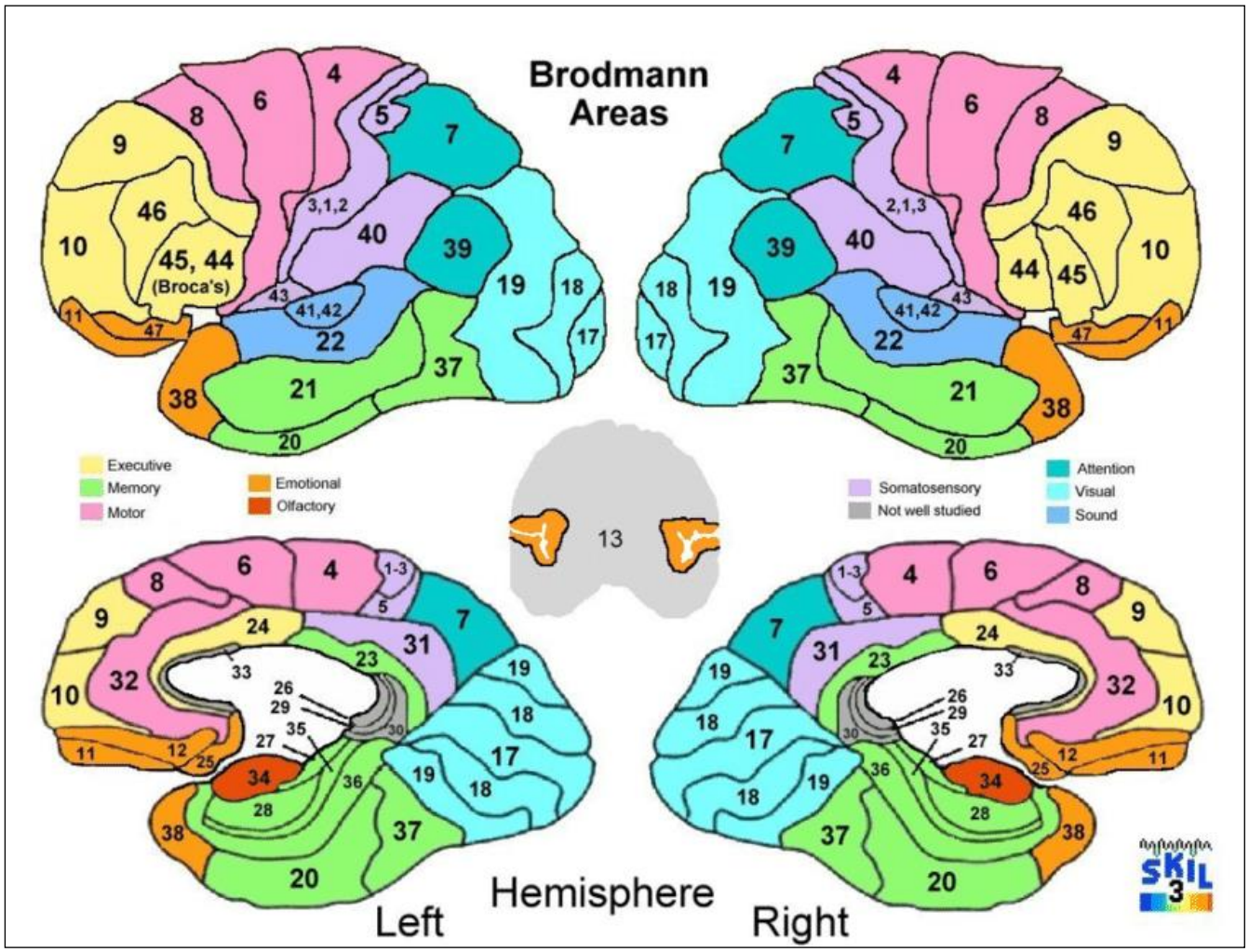

Figure 10 : Representation of functional cortex zones named Brodmann areas (BA) on medial and lateral side of the both hemispheres, and their major psychomotor roles (from : brainm.com/software)

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Table 2 : Studies quality assessment (CD = cannot determine ; NA = not applicable ; NR = not reported)

	1.Hinshaw D. B. Jr *et al.*, 1984	2. Gonzalez J. G. *et al.*, 1988	3. Oatridge A. *et al.*, 2002	4. Miki Y. *et al.*, 2005	5. Kim P. *et al.*, 2010a	6. Barba-Müller E., 2015	7. Lisofsky N. *et al.*, 2016	8. Hoekzema E. *et al.*, 2017	9. Kim P. *et al.*, 2018	10. Carmona S. *et al.*, 2019	11. Lisofsky N. *et al.*, 2019	12. Luders E. *et al.*, 2020	13. Hoekzema E. *et al.*, 2020	14. Luo H. *et al.*, 2020	15. Zhang K. *et al.*, 2020	16. Orchard E. R. *et al.*, 2020	17. Martinez-Garcia M. *et al.*, 2021	18. Moses-Kolko E. L *et al.*, 2021
Research question or objective clearly stated?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Population clearly specified and defined?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Participation rate of eligible persons > 50%?	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	NR	YES	YES
Subjects recruited from similar populations ? Inclusion/exclusion criteria prespecified and uniformly applied?	NO	NO	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES
Sample size justification, power description, or variance and effect estimates provided?	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Exposure(s) of interest measured prior to the outcome(s) being measured?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Timeframe sufficient to see an association between exposure and outcome if it existed?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Study examines different levels of the exposure as related to the outcome ?	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES
Exposure measures clearly defined, valid, reliable, and implemented consistently across all study participants?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Exposure(s) assessed more than once?	NO	NO	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES	NO	YES	NO	YES	NO
Outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Outcome assessors blinded to the exposure status of participants?	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Loss to follow-up after baseline 20% or less?	NA	NA	YES	YES	YES	YES	NA	NO	NA	YES	YES	YES	NO	NA	YES	NA	NO	NA
Key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Good (>75% yes), fair (between 50% and 75%) or poor (<50% yes) quality of study	50% POOR	71,43% FAIR	78,57% GOOD	92,86% GOOD	78,57% GOOD	85,71% GOOD	71,43% FAIR	78,57% GOOD	78,57% GOOD	71,43% FAIR	85,71% GOOD	85,71% GOOD	78,57% GOOD	71,43% FAIR	85,71% GOOD	71,43% FAIR	71,43% FAIR	71,43% FAIR

Table 3 : Detailed results of included studies' analyses

Included articles by chronological order of publication (study type)	Test group(s)	Control group	MRI measurement methodology	Main judgment criterion = nature and location of cerebral modifications (± cellular mechanism(s))	Changes beginning and persistence duration	Consequences on cognitive function	Relationship with maternal behavior and mother-child attachment	Limites, bias and onset of reflection
② Gonzalez D. G. *et al.*, 1988 Mexico (controlled cross-sectional study)	32 primi F (Â = 20y) : Groupe I = <12 WPy (n = 10) Groupe II = between 13 and 26 WPy (n = 11) Groupe III = >27 WPy (n = 11)	20 nulli F without hormonal contraception, at D5 of their menstrual cycle (Â = 23y)	Only one blind measure, by an experienced independent radiologist	Correlation between PG volume ↗ and gestational age (dimensions ↗ in vertical, transverse and anteroposterior axes), increased convexity of the PG's upper edge According to other studies, PG size ↗ is due to number and size ↗ of lactotroph cells (which secrete prolactin for breastfeeding after birth) because of high estrogen levels during Py	emergence during Py	/	/	No possibility of comparison with anterior state Great interpersonal variability No measure before or during Py (control group role ?) neither in PP Statistically different ages between control and test groups ?
③ Oatridge A. *et al.*, 2002 England (uncontrolled cohort study)	9 pregnant F (Â = 31y)	/	- before Py (2) - 15 WPy (2) - 20 WPy (4) - 25 WPy (3) - 30 WPy (4) - 35 WPy (1) - be4 Bth (9) - 6 WPP (9) - 24 WPP (8) - 40 WPP (3) - 52 WPP (3)	Before birth, whole-brain volume ↘, ventricles and PG volumes ↗ After birth, that's the opposite, whole-brain volume ↗, ventricles and PG volumes ↘	Modifications appear since Py onset, reach a maximum at term then regress during PP, mostly before 6W PP and until to 24W PP	no particular regions highlighted with brain activity imaging	/	Healthy pregnant F group is the control group for preeclamptic pregnant F, there is no control group of healthy non pregnant F without hormonal contraception F of healthy pregnant group are primi or multi ? All F didn't benefit of each imaging session and too small samples
④ Miki Y. *et al.*, 2005 Japan (uncontrolled cohort study)	12 breastfeeding primi mothers (Â = 28y) until to 6M PP, 8 mothers weaned their babies during the study	/	from 2W PP, one measure every 2W to 2M (interval of 2W to 1M if weaning) until to about a Y	Correlation between PG volume ↘ and time elapsed since birth Adenohypophysis signal strength ↘ but no significant difference of neurohypophysis signal PG upper edge convexity ↘	in PP	/	/	No control group with nulli F without hormonal contraception Measurement only from 2W PP, no measure before and during Py, neither during I/EPP. Random time-gaps between measurements
⑤ Kim P. *et al.*, 2010a USA (uncontrolled cohort study)	11 primi and 8 multi F (Â = 33y)	/	- 2-4 W PP (MRI and YIPTA-R interview) - 3-4 M PP	GM volume ↗ in : - inf/sup pariet lobe, **precuneus**, med front gyrus, postcent gyrus, **ACC**/med/**PCC** (**L**/**R**) BA 3/5/6/7/8/31/40 - inf/mid front gyrus, precent gyrus (**L**) BA 6/9/47 - thalamus (**R**) - hypothal, subst nigra, **caudate**, mammil body (**L**/**R**) - **amygdala**, putamen, GP, **ACC**, **parahippo gyrus**, **insula** (**R**) - mid front gyrus, precent gyrus (**R**) - mid and sup front gyrus (**R**) - ant and post lobes of cerebellum (**R**) - sup temp gyrus, **insula** (**L**) - brainstem (pons and medulla) (**L**) - **insula** (**R**) - post lobe of cerebellum (**L**/**R**) - **parahippo gyrus** (**R**)	in PP	/	Positive perception and thinks about babies, effect on motivation and maternal behaviour	No control group with non-pregnant nulli F without hormonal contraception No measure before or during Py, neither in immediate nor after 4M PP No differentiation between primi F and multi F results No YIPTA-R interview at 3-4 M PP

⑥ Barba-Müller E., 2015 Spain (controlled cohort study)	25 primi F (Â = 33y)	20 nulli F (Â = 31y)	-before Py (pre-session) -at 2,5 M PP (post-session) time-lapse = 15,5 M ± 3,5 M between both measures	PG volume ↗, no GM volume ↗ but ↘ of GM volume in : - **PCC**, **precuneus**, STS, inf/mid/sup temp CTX, fusiform gyrus, hippo and **parahippo gyrus** (**L**/**R**) - inf/mid/sup front CTX, **ACC** and **insula** (**L**/**R**) - inf/mid front CTX and **insula** (**R**) - mid/sup front CTX (**R**) - inf front CTX and sup temp CTX (**R**) - post cerebellar lobe (**L**/**R**)	emergence during Py	No difference in cognitive abilities or empathy according to tests carried out but areas where GM diminished contain the ToM and DMN	Learn to decode and respond in the best way to baby's cues and needs	No measure during Py neither between birth and 2,5 M PP So impossibility to know if GM volume has only decreased or if changes reach a maximum before start to regress
⑦ Lisofsky N. *et al.*, 2016 Germany (controlled cross-sectional study)	30 primi F (Â = 28y)	30 nulli F without hormonal contraception at D1-D10 of their menstrual cycle (Â = 28y)	only 1 time during the 2 first M PP	striatum GM ↘ (which contains putamen) in **L** +++ and **R** ± no significant difference in hippo correlation between prenatal oestrogens high level and importance of putamen GM ↘ but not for postnatal level	in PP	cognitive navigation, performance ↘ more difficulties for learning route	/	No measure before or during Py, so can't compare with anterior state Cognitive tests were done at ninth M of Py while MRI were acquired more or less long time after birth, and what is more not at the same PP moment for all F Too large measurement period and great interpersonal variability No correlation curve between importance of the changes and time since birth
⑧ Hoekzema E. *et al.*, 2017 a continuation of Barba-Müller E., 2015 Spain (controlled cohort study)	25 primi F (Â = 33y)	20 nulli F (Â = 31y)	- before Py (pre-session) - at 2,5 M PP (post-session) - and about 2Y after the post-session (post + 2Y)	No GM volume ↗ GM volume ↘ in : - STS, mid/sup temp gyrus, **parahippo gyrus** (**R** +++/**L**) - **precuneus**, **ACC** (**R**/**L**) - med sup front CTX, **ACC**, **med OFC** (**R**/**L**) - inf front gyrus (**R** +++/**L**) - **inf orbitofront gyrus**, inf front gyrus, **insula** (**L**) - mid and sup front gyrus (**L**) - fusiform gyrus, inf temp gyrus (**R**/**L** +++) - hippo, **parahippo gyrus** (**L**)	emergence during Py Persistence of changes for at least two years after birth	Brain activity increased in regions where the ↘ in GM volume is observed and correspond to the ToM No difference to cognitive test results	Ease to decode the needs of a newborn who is expressed only through crying/facial expressions/ attitude/behavior Better appreciation of mother-child relationship and attachment quality	No measure during Py, neither between birth and the post-session, nor at regular time-lapse during the 2Y after post-session
⑨ Kim P. *et al.*, 2018 USA (uncontrolled cross-sectional study)	39 primi F (Â = 24y)	/	one single measure during first 7 M PP (at average 4 M)	correlation between CT ↗ importance and time elapsed since birth in : - sup front gyrus, **med/lat orbitofront gyri** (**L**) BA 10 - lat occ gyrus, inf/mid temp gyrus, inf pariet gyrus (**L**) BA 19 - fusiform gyrus, lat occ gyrus (**R**) BA 19 - sup front gyrus (**R**) BA 6 - mid caudal front gyrus, precentral gyrus (**R**) BA 8 - lat occ gyrus, inf pariet gyrus, mid temp gyrus (**R**) BA 18	in PP	/	positive appreciation of the effectiveness felt by F in mothering	No control group of nulli F without hormonal contraception No following up, measurements were not done through 6M PP on the same patients many times but on different patients with an unique MRI (great interpersonal variability) No correlation curve showing the extent of change as a function of time since birth Self-judgment bias and optimistic significativity threshold, real parental self-efficacy or is that a consequence of environnement, culture or supporting entourage ? Sleep lack impact ?

⑩ Carmona S. *et al.*, 2019 ; further study of Hoekzema E. *et al.*, 2017 Spain (controlled cohort study)	25 primi F (Â = 33y)	20 nulli F (Â = 31y)	- before Py (pre-session) - at 2,5 M PP (post-session) time-lapse = 15,5 M ± 3,5 M between both measures	Modifications expressed in %/M : • whole-brain volume : - 0,1 • cortical volume : - 0,2 • total cortical thickness : - 0,1 • actual cortical surface : - 0,075 • related cortical surface : - 0,05 • gyrification index : - 0,05 • sulcal cortical thickness : - 0,1 • sulcal cortical surface : - 0,15 • sulcal depth : - 0,05 • sulcal length : - 0,05 • sulcal width : + 0,4 • gyral WM thickness : 0	emergence during Py	Analogy with importance of brain plasticity observed during puberty Correlation with high hormone levels during these two periods of a woman's life	/	Obtained values are expressed in average percentage related to months number between both measurements, including the months between the first measure and the conception, and between the birth and the second measure, not calculated only on the nine months of Py Therefore very little representative of the actual appearance speed of changes, are they really linear ?
⑪ Lisofsky N. *et al.*, 2019 Germany (controlled cohort study)	24 primi F (Â = 28y)	24 nulli F without hormonal contraception since at least 6M (Â = 25y)	Time 1 : average 1-2M PP Time 2 : average 4- M PP	GM volume smaller in news mothers than in control group (except for Crus I/II cluster) GM volume ↗ between the both measures in : - **ACC**, **ventromed PFC** (**L**/**R**) - mid front gyrus (**R** +++/**L**) BA 9/10 - cerebellar number VI lobe (**L**) - mid front gyrus (**L**) BA 8 - cerebellar Crus I/II (**L**) - **accumbens basal ganglia** (**L**) Negative correlation between age of F and changes extent in **ACC**	in PP	no difference in cognitive abilities between both groups but results ↗ between T1 and T2	/	Statistically different ages between control and test groups No measure before or during Py or in I/EPP, no possibility to compare with anterior state, to know exactly when changes reach their maximum Results ↗ for cognitive tests is due to a test-retest effect
⑫ Luders E. *et al.*, 2020 Country ? (uncontrolled cohort study)	7 primi F 7 multi F (Â = 33y)	/	at 24-48H PP and at 4-6W PP	GM volume ↗ in : **L** hemisphere : - precent and postcent gyri - thal and hypothal - perisylvian region - inf front gyrus - front and pariet operculum - secondary somatosensorial operculum - **post insula** - **caudate** **R** hemisphere : - inf and mid front gyrus - inf and sup pariet lobe - intrapariet sulcus - inf pariet lobe - **insula** - temp lobe - thal and hypothal - **precuneus** - mid occ gyrus	in PP	/	Analogy with reviews on women and animal studies, responses to babies signals and mothering behaviors are governed by impacted brain areas	No control group with nulli F without hormonal contraception No measure before and during Py, so no possibility to compare with anterior state No differentiation or primi F and multi F results
⑬ Hoekzema E. *et al.*, 2020 ; further study of Hoekzema E. *et al.*, 2017 Spain (controlled cohort study)	25 primi F (Â = 33y)	20 nulli F (Â = 31y)	- before Py (pre-session) - at 2,5 M PP (post-session) - and about 2Y after the post-session (post + 2y)	ventral striatum (which contains **accumbens nucleus**) volume ↘ in **L** + and **R** +++		Emergence during Py Persistence of changes for at least two years after birth	Emotions regulation More empathy ToM and reward circuit activation	/	No measure during Py neither in I/EPP
⑭ Luo H. *et al.*, 2020 China (controlled cross-sectional study)	9 primi F (Â = 20 - 34y)	8 nulli F (Â = 20 - 34y)	at D1 PP	CV ↘ in (p < 0,05) : - dorsolat sup front gyri (**L**/**R**) - med cing/paracing gyri (**L**/**R**) - med sup front gyri (**L**) - **post cing gyrus** (**L**) - postcent gyrus (**L**) - **caudate** (**R**)	CV ↘ in (p = 0,05) : - **post cing gyrus** (**R**) - supramarg gyrus (**L**/**R**) - lenticul nucleus, pallidum (**L**) - supramarg and angular gyri (**L**)	emergence during Py	activity ↗ in cent pariet area and ↘ activity in temp lobe and temp-pariet junction in L hemisphere +++	/	No measure before and during Py, so no possibility to compare with anterior state No measure later during the PP

				- inf occ gyrus (**R**)					
⑮ Zhang K. *et al.*, 2020 China (controlled cohort study)	35 mothers (22 of which will be monitored remotely) (Â = 30y)	26 non mothers (Â = 26,5y)	Scan session 1 = mothers at 1Y PP (babies age = 8M ± 4M) Scan session 2 = mothers at 2Y PP (babies age = 28,5M ± 4M) (time-lapse = 705D ± 8,5D between both measures	Mothers at 1Y PP VS non mothers : - GM volume ↘ in : * mid/sup front gyri (**L**) BA 10 * med sup front gyri (**R**/**L**) BA 6/8/9/10, **ACC** (**L**) * Putamen, lentiform nucleus, lat GP (**R**) * sup temp gyrus (**L**) BA 19/22 * lentiform nucleus, putamen, **insula**, claustrum, lat GP (**L**) BA 13/47 * **orbital**/rectal gyri (**R**) BA 11 * **insula** (**L**) BA 13/41 * **parahippo gyrus** (**L**) * med sup front gyri (**R**) BA 8 * med front gyrus (**L**) * mid temp gyrus (**L**) BA 21 * inf front gyrus (**R**) BA 47 - WM volume ↗ in : * lentiform nucleus, putamen, **insula**, claustrum (**L**) BA 13 *ant/post cerebellar lobes, fusiform gyrus (**R**) BA 37 - GI ↗ in **med/lat OFC** (**R**) - CT ↘ in precent gyrus (**R**)	Mothers at 1Y PP VS 2Y PP : - GM volume ↘ in : * med sup front gyri, precent gyri, inf/mid front gyri (**R**/**L**) BA 6/8/9 * postcent gyus, sup pariet lobule (**L**) BA 2/5/7 * postcent gyrus , paracent lobule, **precuneus** (**R**) BA 2/3/4/5/6/7 * thal (**R**/**L**) * precent gyrus (**L**) BA 4/6 * **caudate** (**L**) * mid front gyrus (**L**) BA10/46 * **insula** (**L**) BA 13 * ant/post cereb lobes (**R**/**L**) * **caudate** (**R**) * precentral gyrus (**L**) BA 6 * **parahippo gyrus** (**R**) BA 28 - WM volume ↗ in : * inf pariet lobule, **insula**, postcent gyrus (**L**) BA 13 * inf pariet lobule, **insula**, postcent gyrus (**R**) BA 13 * mid/sup temp gyrus, supramarg/angular gyri (**R**) BA 22/39 * **insula** (**L**/**R**) BA 13 * sup temp gyrus, inf pariet lobule (**R**) BA 13 * mid/sup temp gyrus (**L**) BA 39 - No difference in GI - CT ↘ in **precuneus**, inf pariet CTX (**L**)	emergence during Py Persistence of changes for at least two years after birth	More empathy and listening skills put oneself more easily in other people's shoes Reward circuit activation	High sensitivity to signals and crying, allowing better interpretation of baby's needs, better caregiving	Significant age difference between control and test groups No measure before or during Py, so no possibility of comparison with anterior state in mothers
⑯ Orchard E. R. *et al.*, 2020 Australia (controlled cross-sectional study)	235 multi post-menopausal F (whose 20 primi F) (Â = 74y)	25 nulli post-menopausal F (Â = 72,5y)	Several tens of years after the last birth	Modification of CT according to parity : - ↗ **parahippo gyrus**(**R**) - ↘ **precuneus** (**R**) - ↘ cuneus (**L**) - ↘ calcarine sulcus (**L**)	Modification of CT of mothers VS non-mothers : - ↘ calcarine sulcus (**R**) - ↘ caudal and mid front gyrus (**L**)	emergence during Py Persistence until late age	Better cognitive functions (ex: memory) for multi compared to primi / nulli but no difference between nulli and primi	Response to children's facial expressions, parent-child interaction	Patients from controlled clinical trial on low dose aspirin effect Nulli group smaller than multi group Primi F group is also part of the multi F group and there is no differentiation in parity levels for multi F Information bias on Py/birth(s) progress Very long time between birth(s) and MRI, experiential (with grandchildren for ex.), environmental and/or genetic

									factors to take into account, in any case no neuropsychological disorders
⑰ Martinez-Garcia M. *et al.*, 2021 continuation of Hoekzema E. *et al.*, 2017 Spain (controlled cohort study)	F with Py project and mothers once -Pre-session (n = 25 ; Â = 34y) -Post-session (n = 25 ; Â = 35y) -Post + 6 years (n = 7 ; Â = 40,5y)	F without Py project and still childless -Pre-session (n = 22 ; Â = 31y) -Post-session (n = 21 ; Â = 32y) -Post + 6 years (n = 5 ; Â = 39y)	- before Py (pre-session) - at 2,5 M PP (post-session) - and about 6Y after the post-session (post + 6 y)	GM volume ↘ in : - fusiform gyrus (**L**/**R**) - inf, mid and med frontal CTX (**L**/**R**) - **precuneus,** sup temp CTX (**R**)		emergence during Py Persistence for at least 6Y after birth	Modification in the maternal circuit = reward circuit + social interaction Better memory for multiparous F	Correlation between high scores on the "pleasure in the interaction" item of the MPAS and importance of GM volume ↘	No measurement during Py or I/E PP No measurement at regular intervals during the 6Y following the post-session Very small population after 6 years Long time between birth(s) and MRI, experiential, environmental and / or genetic factors to take into account
⑱ Moses-Kolko E. L *et al.*, 2021 USA (uncontrolled cross-sectional study)	137 primi (Â = 20.5y)	/	one single measure at average 4M	Significant decrease in hippocampal GM volume, not significant decrease in **amygdala** and **vmPFC**		in PP	stress circuit	inversely associated with positive maternal caregiving	All women were recruited because of their early life circumstances with lots of stress, no supporting for child abuse (84% minority race) but only 8.8% of women present postpartum depression at scan time No control group of nulli F without hormonal contraception No measure before or during Py, neither at several moments of PP, so no possibility to compare with an anterior state or to know the persistence duration of changes

Table 4 : Summary of brain adaptations during pregnancy and postpartum

Articles	Brain changes location	Before Py	1st trimester of Py	2nd trimester of Py	3rd trimester of Py	Just before birth	IPP (D0 – D2)	Late PP (W2 – W6)	W6 - M6 after birth	M6 - 1 year after birth	1-2 years after birth	6 years after birth	several tens of years after birth(s)
② Gonzalez D. G. *et al.*, 1988	PG volume		↗ W8 (n = 10)	↗ W21 (n = 11)	↗ W36 (n = 11)								
	PG upper side convexity		↗ W8 (n = 10)	↗ W21 (n = 11)	↗ W36 (n = 11)								
③ Oatridge A. *et al.*, 2002	Whole-brain volume	= (n = 2)	↘ W15 (n = 2)	↘ W20 (n = 4) W25 (n = 3)	↘ W30 (n = 4) W35 (n = 1)	↘ 9th M (n = 9)		↗ W6 (n = 9)	↗ M5 (n = 8)	= M9 (n = 3) Y1 (n = 3)			
	Ventricles volume	= (n = 2)	↗ W15 (n = 2)	↗ W20 (n = 4) W25 (n = 3)	↗ W30 (n = 4) W35 (n = 1)	↗ 9th M (n = 9)		↘ W6 (n = 9)	↘ M5 (n = 8)	= M9 (n = 3) Y1 (n = 3)			

	PG volume	= (n = 2)	↗ W15 (n = 2)	↗ W20 (n = 4) W25 (n = 3)	↗ W30 (n = 4) W35 (n = 1)	↗ 9th M (n = 9)		↘ W6 (n = 9)	↘ M5 (n = 8)	= M9 (n = 3) Y1 (n = 3)			
④ Miki Y. *et al.*, 2005	PG volume							↘ W2 (n = 13)	↘ M4 (n = 13)	↘ M8 (n = 13) Y1 (n = 12)			
	Adenohypophysis signal intensity							↘ W2 (n = 13)	↘ M4 (n = 13)	↘ M8 (n = 13) Y1 (n = 12)			
	Neurohypophysis signal intensity							= W2 (n = 13)	= M4 (n = 13)	= M8 (n = 13) Y1 (n = 12)			
	PG upper side convexity							↘ W2 (n = 13)	↘ M4 (n = 13)	→ M8 (n = 13) Y1 (n = 12)			
⑤ Kim P. *et al.*, 2010a	Cortex volume							W2/W4 (n = 19)	↗ M3/M4 (n = 19)				
	Thalamus/hypothalamus volume							W2/W4 (n = 19)	↗ M3/M4 (n = 19)				
	Cerebellum volume							W2/W4 (n = 19)	↗ M3/M4 (n = 19)				
	Basal ganglia volume							W2/W4 (n = 19)	↗ M3/M4 (n = 19)				
	Brainstem (pons and medulla)							W2/W4 (n = 19)	↗ M3/M4 (n = 19)				
⑥ Barba-Müller E., 2015	Cortex volume	= (n = 25)							↘ M2,5 (n = 25)				
	Cerebellum volume	= (n = 25)							↘ M2,5 (n = 25)				
	PG volume	= (n = 25)							↗ M2,5 (n = 25)				
	Hippocampus volume	= (n = 25)							↘ M2,5 (n = 25)				
⑦ Lisofsky N. *et al.*, 2016	Basal ganglia (striatum) volume							↘ First 2M (n = 30)					
	Hippocampus volume							= First 2M (n = 30)					
⑧ Hoekzema E. *et al.*, 2017	Cortex volume	= (n = 25)							↘ M2,5 (n = 25)		↘ Y2 ± 6M (n = 11)		

	Hippocampus volume	= (n = 25)							↘ M2,5 (n = 25)		↗ Y2 ± 6M (n = 11)		
⑨ Kim P. *et al.*, 2018	Cortical thickness							↗ M1 – M7 (n = 39)					
⑩ Carmona S. *et al.*, 2019	Whole-brain volume	= (n = 25)							↘ M2,5 (n = 25)				
	Cortex volume	= (n = 25)							↘ M2,5 (n = 25)				
	Cortical thickness	= (n = 25)							↘ M2,5 (n = 25)				
	Gyrification index	= (n = 25)							↘ M2,5 (n = 25)				
⑪ Lisofsky N. *et al.*, 2019	Cortex volume							↗ M1/M2 (n = 24)	↗ M4/M5 (n = 24)				
	Cerebellum volume							↗ M1/M2 (n = 24)	↗ M4/M5 (n = 24)				
	Basal ganglia (accumbens) volume							↗ M1/M2 (n = 24)	↗ M4/M5 (n = 24)				
⑫ Luders E. *et al.*, 2020	Cortex volume						(n = 14)	↗ W4/W6 (n = 14)					
	Thalamus/hypothalamus volume						(n = 14)	↗ W4/W6 (n = 14)					
	Basal ganglia (caudate) volume						(n = 14)	↗ W4/W6 (n = 14)					
⑬ Hoekzema E. *et al.*, 2020	Basal ganglia (striatum) volume	= (n = 25)							↘ M2,5 (n = 25)		→ Y2 ±4M (n = 11)		
⑭ Luo H. *et al.*, 2020	Cortex volume						↘ (n = 9)						
⑮ Zhang K. *et al.*, 2020	Cortex volume									↘ M8 ± 4M (n = 35)	↘ Y2 ± 4M (n = 22)		
	Cortical thickness									↘ in precentral ctx M8 ± 4M (n = 35)	↘ in precuneus and inf pariet ctx Y2 ±4M (n = 22)		
	Thalamus									= M8 ± 4M (n = 35)	↘ Y2 ±4M (n = 22)		

	Basal ganglia volume									↘ GM M8 ±4M (n = 35)	↘ caudate GM Y2 ±4M (n = 22)		
	Gyrification index									↗ in med/lat orbitofrontal ctx M8 ±4M (n = 35)	→ Y2 ±4M (n = 22)		
	Cerebellum volume									↗ (WM) M8 ±4M (n = 35)	↘ (GM) Y2 ±4M (n = 22)		
	White matter volume									↗ in BG and fusiform gyrus M8 ±4M (n = 35)	↗ Y2 ±4M (n = 22)		
⑯ Orchard E. R. *et al.*, 2020	Cortical thickness												↘ others ROI (n = 235) ↗ parahippo gyrus (n = 235)
⑰ Martinez-Garcia M. *et al.*, 2021	Cortex volume	= (n = 25)							↘ M2,5 (n = 25)			↘ Y6 ±7M (n = 7)	
⑱ Moses-Kolko E. L *et al.*, 2021	Hippocampus volume								↘ M4 (n = 137)				

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Mémoire de fin d'études de sage-femme de Anaïs BAGUE MORANDINI – 2022

Adaptations anatomiques cérébrales générées par la grossesse, une revue systématique de littérature.

Articles de 1984 à 2021.

Contexte : le cerveau maternel est le siège de nombreuses adaptations hormonales, cognitives et psychologiques pendant la grossesse et le post-partum. Plus récemment, des études ont montré des modifications anatomiques cérébrales durant cette période particulière de la vie des femmes.

Objectif(s) : Cette revue visait à compiler les connaissances sur les adaptations anatomiques du cerveau maternel pendant la grossesse et le post-partum. Les objectifs secondaires étaient de mettre en évidence le moment d'émergence et la durée de ces modifications, quelles et comment les fonctions cérébrales sont impactées, et enfin leur lien avec les comportements maternels et les fonctions cognitives.

Méthode : cette revue systématique a été menée sous le modèle PRISMA 2020. Des mots-clés comme plasticité neuronale, grossesse et comportement maternel ont été utilisés sur différentes bases de données telles que NCBI ou PLOS. Dix-huit articles dont les données (type d'étude, qualité, composition des groupes, fréquence des mesures, régions cérébrales impactées, etc.) ont été extraites.

Résultats : les données montrent que l'hypophyse augmente de taille pendant la grossesse, tandis que d'autres structures cérébrales telles que le cortex, les noyaux gris centraux, le cervelet, l'hippocampe, le thalamus ou encore l'hypothalamus diminuent en volume. Ces modifications améliorent les performances mémorielles, les qualités sociales et les compétences de caregiving des mères. Il semble que ces adaptations persistent plusieurs mois, voire même des années après la naissance selon quelques études, d'autres équipes de recherche sont par ailleurs en désaccord avec cette conclusion.

Conclusion : concernant les changements au cours du post-partum, les conclusions des études incluses sont contradictoires en termes de croissance ou décroissance des volumes et de persistance ou de régression de ces adaptations. En tout cas, on ne peut conclure à une perte de substance cérébrale, ne connaissant pas les mécanismes sous-jacents ni la densité cellulaire des structures impactées mais il est certain qu'il n'y a en réalité pas ou peu de diminution des capacités cognitives, bien au contraire.

Mots clés (3)

plasticité cérébrale, grossesse, post-partum, comportement maternel