



Perinatal SSRI medications and offspring hippocampal plasticity interaction with maternal stress and sex

Jodi L. Pawluski, Mary Gemmel

► To cite this version:

Jodi L. Pawluski, Mary Gemmel. Perinatal SSRI medications and offspring hippocampal plasticity interaction with maternal stress and sex. *Hormones-International Journal of Endocrinology and Metabolism*, 2018, 17 (1), pp.15-24. 10.1007/s42000-018-0011-y . hal-01863048v1

HAL Id: hal-01863048

<https://univ-rennes.hal.science/hal-01863048v1>

Submitted on 30 Aug 2018 (v1), last revised 18 Sep 2018 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Perinatal SSRI medications and offspring hippocampal plasticity: interaction with maternal stress and sex

Abbreviated title: Perinatal SSRIs and hippocampus

Jodi L. Pawluski^{1*} and Mary Gemmel²

¹Univ Rennes, Inserm, EHESP, Irset (Institut de Recherche en Santé, Environnement et Travail), UMR_S1085, F-35000, Rennes, France.

²Department of Biological Sciences, Ohio University, Athens, Ohio, USA

***Corresponding Author:** Jodi L. Pawluski, Ph.D., Université de Rennes 1, Campus Villejean, 9 avenue du Prof. Leon Bernard, 35000 Rennes, FRANCE, Phone: +33(0)2 23.23.41.90, Email address: j.pawluski@gmail.com / Jodi-lynn.pawluski@univ-rennes1.fr

Acknowledgements: JLP is funded by a Brain & Behavior Foundation NARSAD Young Investigator Grant.

Abstract

There is a growing use of selective serotonin reuptake inhibitor antidepressant medications (SSRIs) during the perinatal period to treat maternal affective disorders. Perinatal SSRI exposure can have a long term impact on offspring neuroplasticity and behavioral development that remains to be fully elucidated. This mini review will summarize what is known about the effects of perinatal SSRIs on plasticity in the developing hippocampus, taking into account the role that maternal stress and depression may have. Emerging clinical findings and research in animal models will be discussed. In addition, sexually differentiated effects will be highlighted, as recent work shows that male offspring are often more sensitive to the effects of maternal stress, whereas female offspring can be more sensitive to perinatal SSRIs. Potential mechanisms behind these changes and aims for future research will be discussed. Understanding the impact of perinatal SSRIs on neuroplasticity will provide better insight into the long-term effects of such medications on the health and well-being of both mother and child, and may improve therapeutic approaches for maternal mood disorders during the perinatal period.

Key words: Antidepressants, Perinatal Depression, Prenatal Stress, Neurogenesis, Hippocampus, Adolescence, Sex Differences, 5-HT, serotonin

1. Introduction

Up to 20% of women are diagnosed with depression or anxiety during the perinatal period.¹⁻⁴ These affective disorders can have detrimental effects for both the mother and developing child and as such, treatment is needed.^{4,5} Many antidepressant treatments are available to treat maternal affective disorders, with selective serotonin reuptake inhibitor medications (SSRIs) being the recommended first line of treatment.^{4, 6, 7} SSRIs, with the exception of paroxetine, are considered safe for use during pregnancy as they have no major teratogenic effects on the fetus.⁸ SSRI prescription rates for pregnant women in industrialized countries (including Canada, Iceland, Denmark, Sweden, UK, Italy, the Netherlands, and France) range between 2-7% in Canada and Western European countries, and between 5-13% in Australia and the USA.^{6, 7, 9-12} These medications are expected to promote maternal mental health and thus promote the health and wellbeing of both the mother and child.¹³ However, SSRIs can cross the placenta and, to a lesser degree, are found in breast milk, modulating the serotonergic environment for the developing fetus and having potentially long-term effects on neurodevelopment.¹⁴⁻¹⁷

Clinical research has shown that children exposed to SSRIs prenatally are at increased risk for behavioral abnormalities including attentional deficits, neuropsychiatric disorders, and neurodevelopmental disorders.¹⁸⁻²⁰ As the hippocampus is a key mediator of behavior and cognition, and receives substantial **serotonergic innervation**, such effects are likely linked to SSRI-related changes in hippocampal development. Therefore, this mini review will focus on how perinatal SSRIs affect plasticity in the developing hippocampus. First, we will briefly review how SSRIs during the perinatal period may alter the developing serotonergic system, and then we will review what is known about perinatal SSRI effects on biomarkers of neuroplasticity in clinical studies and measures of hippocampus plasticity from work in laboratory rodent models. Early life exposure to maternal mental illness, in the presence of SSRIs, can also have a persistent effects of offspring neurobehavioral outcomes.^{21, 22} Thus, the implications of both perinatal SSRIs and maternal **stress-related disorders will be discussed in terms of offspring outcomes, where possible**.^{23, 24} Understanding the long-term effect of perinatal SSRIs on hippocampus plasticity will aid in understanding the risks and benefits of exposure to these medications during the perinatal period.

2. Serotonin, SSRIs and the developing hippocampus

During development, serotonin (5-hydroxytryptamine or 5-HT) plays an important role in regulating proliferation, migration, and differentiation of neurons as well as axonal connectivity and synaptic pruning.²⁵⁻²⁷ A number of studies indicate that serotonin signaling during early life is critically involved in the development of neuronal circuits.²⁷⁻³² Therefore, any changes to serotonin levels and/or serotonergic system functioning during the perinatal period could disrupt the development of not only the serotonergic system in infants, but also countless brain regions which receive serotonergic input, such as the hippocampus.

SSRIs act by blocking the serotonin transporter (SERT) on the presynaptic neuronal membrane and subsequently reduce serotonin reuptake, increasing serotonin's concentration in the synaptic cleft, and aiding in chemical transmission between neurons which can have mood-stabilizing effects. As perinatal SSRIs target maternal SERT activity, and are present in both the placenta and at much lower levels in breast milk,³³ the use of such medications during pregnancy and lactation suggest an effect on infant neural development. The consequences of perinatal SSRI

exposure may not occur immediately after birth, but may manifest later during childhood, adolescence or even in adulthood.^{14, 34, 35}

Perinatal SSRI treatment can increase hippocampal serotonin levels in adolescent and adult male mice³⁶ and pre-adolescent male and female offspring.³⁷ Interestingly, early life exposure to SSRIs also *normalizes* hippocampal levels of serotonin and serotonin's metabolite 5-hydroxyindolacetic acid (5-HIAA) in prenatally restraint stressed offspring at weaning,³⁸ serotonergic transmission in the ventral hippocampus of adolescent rat offspring after prenatal dexamethasone treatment,³⁹ and serotonin turnover (via 5-HIAA/5-HT ratios) in the hippocampus of prenatally stressed male mouse offspring (Table 1).³⁶ Although not well studied in the hippocampus, perinatal SSRIs do affect serotonergic receptors in cortical and hypothalamic brain regions and thus many layers of the serotonergic system are likely altered with perinatal SSRIs.⁴⁰⁻⁴² It should not be forgotten that maternal stress can also have enduring effects on serotonin, even when combined with perinatal SSRIs: Recently we have shown that pre-gestational chronic unpredictable stress results in significantly reduced hippocampal serotonin levels in pre-adolescent offspring, particularly in female offspring, regardless of perinatal fluoxetine exposure.^{17, 34} Others have shown that pre-gestational stress increases serotonin levels and decreases serotonin transporter expression in the hippocampus of fetal rats,⁴³ and that prenatal stress increases serotonin in weanling offspring, regardless of fluoxetine exposure. Changes in early-life serotonin, and serotonin transporters, may have enduring effects on serotonergic functioning of offspring later in life. Together these findings show that there are long-term effects of both SSRIs and maternal stress on the serotonin system of the hippocampus and that the timing and duration of maternal stress (pre-gestational versus prenatal), as well as offspring age and sex, may mediate these effects on the developing serotonergic system. Therefore, understanding how fluctuations in serotonin and the serotonergic system impact developing neuroplasticity via early life SSRIs, *and* maternal stress, is critical in integrating what we know about hippocampal plasticity in offspring.

3. Perinatal SSRIs and biomarkers of neuroplasticity in Clinical Research

Findings from clinical studies **start** to point to an effect of prenatal SSRIs on fetal and neonatal neurodevelopment by investigating biomarkers in peripheral fluids related to central nervous system development. It has been reported that prenatal SSRIs decreases S100B, an astroglial-specific Ca²⁺-binding protein,^{44, 45} in human neonates at birth.⁴⁶ S100B mediates the positive outgrowth and survival of neurons,^{47, 48} and stimulates glial cell proliferation⁴⁹; therefore, S100B levels in human biological fluids may be a useful indicator of brain maturation and suggest an impact of prenatal drug exposure on neural development.⁴⁶ Since this reduction in S100B occurs when controlling for maternal levels of depression, which serves as a confounding variable in clinical work⁵, such outcomes suggest a significant effect of perinatal SSRI exposure itself on potential markers of neurodevelopment. In addition, reelin levels are decreased in neonates prenatally exposed to SSRIs.⁵⁰ Reelin is an important glycoprotein which plays a critical role in neuronal migration and positioning during neurodevelopment, and these findings further suggest an effect of early life changes in serotonin, via SSRIs, on the brain of developing offspring. Recent imaging data has confirmed that prenatal SSRIs do indeed alter the developing brain, at least in very preterm infants, with prenatal SSRI exposed infants showing decreased activity in the basal ganglia and thalamus.⁵¹ However, due to limitations in the ability of clinical research to investigate central neurodevelopment in SSRI-exposed offspring, animal models have been used to gain insight into the specific effects of perinatal SSRIs on neurogenesis and synaptic plasticity in the

hippocampus. Below is a summary of findings on how perinatal SSRIs affect the developing hippocampus of male and female offspring.

4. Perinatal SSRIs and plasticity in the hippocampus

With clinical work pointing to an effect of perinatal SSRIs on both S100B and reelin, key players in neural migration and plasticity, it is not surprising that there is growing interest in the long-term impact of SSRIs on hippocampal neurogenesis and plasticity. The hippocampus is one of two brain regions where there is a remarkably high rate of neurogenesis throughout the lifespan (the other region being the subventricular zone).^{52, 53} These new neurons, and their ability to form and establish new connections, in the hippocampus play an important role in learning and memory, stress regulation, and, more recently, social behaviours.⁵³⁻⁵⁷ The hippocampus consists of three main regions: cornu ammonis 1 (CA1), cornu ammonis 3 (CA3), and the dentate gyrus, the lattermost being a site with a high rate of continuous neurogenesis in adulthood (Figure 1).^{58, 59} Understanding how neurogenesis and neuroplasticity may shift following perinatal SSRIs will further clarify the role **that** early-life exposures have on neurobehavioral development.

To date, findings highlight long-term effects of perinatal SSRIs on hippocampal plasticity in rodent offspring, particularly after maternal stress. These studies have primarily focused on measures of brain derived neurotrophic factor (BDNF), neurogenesis, and synaptic modifications in the hippocampus. Of particular importance are alterations of BDNF signaling, epigenetic changes at the BDNF gene, and changes in hippocampal plasticity, which have been extensively implicated in the pathophysiology and treatment of mood disorders during adulthood.^{60, 61} Developmental exposure to SSRIs has resulted in long-term impact on BDNF in offspring; Early developmental treatment with fluoxetine can induce long-lasting behavioral impairment, via increased inhibition to stressful events and reduced behavioral despair, accompanied with upregulation of hippocampal BDNF mRNA and TrkB mRNA levels in adult male mice⁶² and a decrease in global DNA methylation in the hippocampus of male rats⁶³. Serotonin transporter (5-HTT) knockout rats, which have elevated levels of serotonin throughout life, display decreased BDNF levels in the hippocampus, concomitant with increased DNA methylation at BDNF promoters IV and VI.⁶⁴ A exact comparison between perinatal SSRI exposure and 5-HTT KO rat models with regards to BDNF levels and methylation status has not been carried, however it is likely that the apparent differences between models on BDNF effects in the hippocampus are due to **the** fact that 5-HTT KO animals have elevated levels of serotonin throughout life and not just during the perinatal period. While this work suggests an effect of perinatal SSRI exposure on BDNF, these three previous studies did not investigate female offspring. We have recently reported in adult female rat offspring that early life exposure to SSRIs (fluoxetine) increases immobility in the forced swim test, decreases hippocampal BDNF exon IV mRNA levels, and increases levels of the repressive histone 3 lysine 27 tri-methylated mark at the corresponding promoter.⁶⁵ We also found a significant negative correlation between hippocampal BDNF exon IV mRNA levels and immobility in the forced swim test with higher hippocampal BDNF mRNA expression being associated with less immobility in the forced swim test.⁶⁵ In adult male offspring, developmental fluoxetine exposure decreased BDNF IV and TrkB mRNA expression in the hippocampus and these changes were not associated with changes in the immobility measure.⁶⁶ In addition, adult male offspring showed an enduring effect of prenatal stress in decreasing hippocampal BDNF IV mRNA expression,⁶⁶ further demonstrating **these effects** sexually differentiated effects following SSRI exposure. Regardless, perinatal SSRIs effects on epigenetic modifications and changes to

BDNF signaling, a critical growth factor required for neuronal growth and development, suggest an impact on additional aspects of neurodevelopment such as neurogenesis and neuroplasticity.

Early life exposure to SSRIs reduces cell proliferation in the hippocampus of adolescent offspring.⁶⁷ However, when combined with a model of maternal stress, early life exposure to SSRIs prevents the effects of maternal stress on hippocampal neurogenesis (immature neurons), in adolescence and adulthood.^{67, 68} These effects occur in both male and female offspring. Others have shown similar effects with postnatal SSRIs preventing the reduction in hippocampal cell proliferation and increased cell death observed in juvenile rat offspring subjected to premature maternal separation.⁶⁹ Developmental exposure to fluoxetine can also have a sexually differentiated effect on the number of immature neurons after maternal corticosterone treatment,⁷⁰ with maternal postpartum fluoxetine increasing the density of immature neurons via doublecortin expression in the hippocampus of adult male offspring, but decreasing the density of immature neurons in adult female offspring. Interestingly, additional reports found no effects of perinatal fluoxetine on hippocampal neurogenesis in the dorsal hippocampus at weaning or in pre-adolescent offspring.^{37, 38} Thus, it appears that after adolescence and puberty, the effects of perinatal SSRIs on hippocampal neurogenesis and plasticity become pronounced and sexually differentiated.

With regards to perinatal SSRI effects on spine densities and synaptic proteins, these effects appear to be primarily dependent on offspring age and sex. For example, early postnatal treatment with fluoxetine reverses the reduction in CA3 spine and synapse density observed in prenatally stressed juvenile and adolescent male mice (females were not studied).³⁶ However, in rat offspring at weaning, we found no effect of early life exposure to fluoxetine on pre-synaptic protein densities (via synaptophysin-immunoreactivity) in the CA3 or dentate gyrus.³⁸ Effects on spine density appear to emerge during pre-adolescence, with pre-adolescent female, not male, rat offspring perinatally exposed to fluoxetine showing increased hippocampal pre-synaptic density in the dentate gyrus.³⁷ These effects are region-specific, with perinatal fluoxetine exposure increasing CA2 density in pre-adolescent females, but decreasing such density in combination with pre-gestational maternal stress exposure. As previously mentioned, although females seem particularly sensitive to the effects of perinatal fluoxetine exposure, male offspring appear particularly sensitive to maternal stress and depression.³⁷ For example, pre-adolescent males, but not females, exposed to perinatal fluoxetine show reductions in pre-synaptic density and immature neurons in the dentate gyrus following pre-gestational maternal stress.³⁷ Furthermore, SSRI exposure appears to affect the developmental trajectory of synaptic protein density, with adult female, but not male, offspring exposed during lactation/suckling to SSRIs showing significantly reduced pre-synaptic density in the dentate gyrus.⁶⁸ This enduring effect of SSRIs on synaptic proteins extends recent work showing that perinatal fluoxetine exposure can reduce perineuronal nets in the CA1 and DG region of juvenile mice hippocampi.⁷¹ In addition, postnatal fluoxetine treatment significantly alters gene expression related to hippocampal synaptic functioning and neurogenesis in selectively bred “Low Responder” rats predisposed for increased anxiety and behavioral abnormalities.⁷² Thus, there is a likely role for perinatal fluoxetine exposure in altering hippocampal synaptic plasticity during development, however these effects of sexually differentiated and age-dependent (Table 1).

5. SSRIs and sex effects on hippocampal plasticity

As mentioned above, there is a persistent effect of sex in mediating perinatal SSRI exposure effects on hippocampal plasticity in adulthood. For example, adult female offspring, but not male offspring, exposed early in life to SSRIs have increased new cell survival, decreased BDNF mRNA expression, and reductions in hippocampal synaptophysin density in the granule cell layer.^{65, 66, 68} Others have shown that maternal postnatal fluoxetine treatment increases adult male immature neuron density in the hippocampus via doublecortin expression, while reducing such density in the adult female hippocampus.⁷⁰ Changes in steroid hormone levels during puberty likely contribute to sex-dependent SSRI sensitivity and structural changes in the hippocampus, as a result of altered estrogen and androgen receptor expression.⁷³⁻⁷⁵ Serotonin plays a key role in sexual differentiation through its role in the development of the hypothalamic–pituitary–gonadal (HPG) axis.^{76, 77} The inhibition of the natural drop in serotonin in the first week of life resulting from SSRI exposure, likely antagonizes the perinatal masculinization effects of testosterone during the second and/or third week postpartum and alters feminization of the brain. Previous work shows that postnatal stimulation of serotonin synthesis, by injection of L-tryptophan, inhibits female sexual behavior and has an inhibitory effect on postnatal “organization” of female sexual behavior as well as on “activation” of female sexual behavior in adulthood.^{76, 77} In addition, a de-feminization of sexually dimorphic brain structures in females results from early-life stimulation of the serotonin synthesis⁷⁸ and, conversely, treatment with parachlorophenylalanine, a serotonin synthesis inhibitor, enhances masculinization and defeminization.^{78, 79} Therefore, sexually differentiated effects of perinatal SSRIs on hippocampal plasticity may be a result of changes to the serotonergic system early in life, as serotonin plays a role in sexual differentiation of the brain via development of the hypothalamic-pituitary-gonadal axis.^{76, 77}

6. The role of maternal stress

As shown above, the effects of perinatal SSRIs can differ in the presence of maternal stress in some regards; the effects of maternal stress are more pronounced and enduring than the effects of SSRIs. For example, maternal stress, regardless of perinatal SSRI exposure, significantly reduces pre-synaptic densities in pre-adolescent male, but not female, offspring and decreases the number of immature neurons in the granule cell layer of dentate gyrus in pre-adolescent and adult male, but not female, offspring.⁶⁸ Interestingly, pre-gestational maternal stress effects on offspring are in agreement with a number of studies showing that *perinatal* maternal stressors reduce hippocampal neurogenesis and plasticity later in life, particularly in males.⁸⁰⁻⁸² In line with this, an increasing amount of clinical research is reporting that child development outcomes are often more affected by maternal depression and associated risk factors prior to conception than by perinatal SSRI exposure.^{5, 21, 22} Thus, a mother’s level of stress and depression during the perinatal period and prior to gestation can have a long-term impact on neurobehavioral outcomes in offspring, regardless, or in addition to, of perinatal SSRI effects. More research is needed to investigate additional therapeutic approaches which treat the effects of perinatal depression in both mothers and offspring.

7. Summary and Future directions

It is clear the perinatal SSRIs can have a long-term effect on plasticity in the hippocampus of exposed offspring. SSRIs can, at times, protect against the effect of maternal stress, have effects

independent of maternal stress, and have effects on offspring that are sexually differentiated. The effects of perinatal SSRIs on hippocampal plasticity may be both direct, due to perinatal drug exposure, and indirect, with effects mediated by maternal care as well as SSRI effects on the placenta.^{17, 83-85} Apart from effects on hippocampal plasticity, a growing body of literature shows that perinatal exposure to SSRIs affect a number of neuroendocrine systems and neurobehavioral outcomes which may be linked to the hippocampus. For example, developmental exposure to SSRIs alters the hypothalamic-pituitary-gonadal axis,^{79, 86} the hypothalamic-pituitary adrenal axis,^{36, 87, 88} and has been linked to poor social behaviors and increased mood disorders in children.³⁴ However, there are also persistent effects of maternal stress and maternal mood on childhood outcomes, even with maternal treatment of SSRIs.^{5, 21, 22}

What is abundantly clear is that untreated maternal depression is not an option for the mother or developing child. SSRIs are the first line treatment for maternal mood disorders and these medications are more effective if combined with psychotherapy. However, there are also a number of treatments available that may also be beneficial to the mother such as psychotherapy alone, parenting classes, exercise and diet change.^{13, 89, 90} Regardless, **the goal is to effectively treat the mother as the risk of untreated maternal depression out way** the risk of the SSRI treatment exposure. However, many pregnant women prescribed SSRIs also remain depressed and anxious and this is detrimental to the mother, child and family. Therefore, SSRI treatment for maternal affective disorders during pregnancy should be treated on an individualized basis, which takes into account depression severity, likelihood of treatment response and probability of adverse fetal effects, and individual patient values and health.⁹¹ The data reviewed here suggest that future treatment for maternal affective disorders, may also need to consider offspring sex, as well as SSRI timing and dosage.

Unfortunately, to date, there is very little research on the neurobiology of maternal mental illness even though 1 in 7 women suffering from perinatal depression or clinical levels of anxiety postpartum.⁴ Thus, more research is needed to understand the mechanisms behind maternal mental illness in order to develop effective and safe treatments for these disorders. Only then will we be able to improve the health and well-being of the mother and child.

Figure Legend

Figure 1. Photomicrographs of A) synaptophysin-immunoreactivity (ir) in the hippocampus (2x) and B) immature neurons in the granule cell layer (doublecortin-ir) (40x) of pre-adolescent rat offspring. CA=cornu ammonis, DG=dentate gyrus. The arrows indicate immature neurons. Scale bar = 200 μ m (A) and 10 μ m (B).

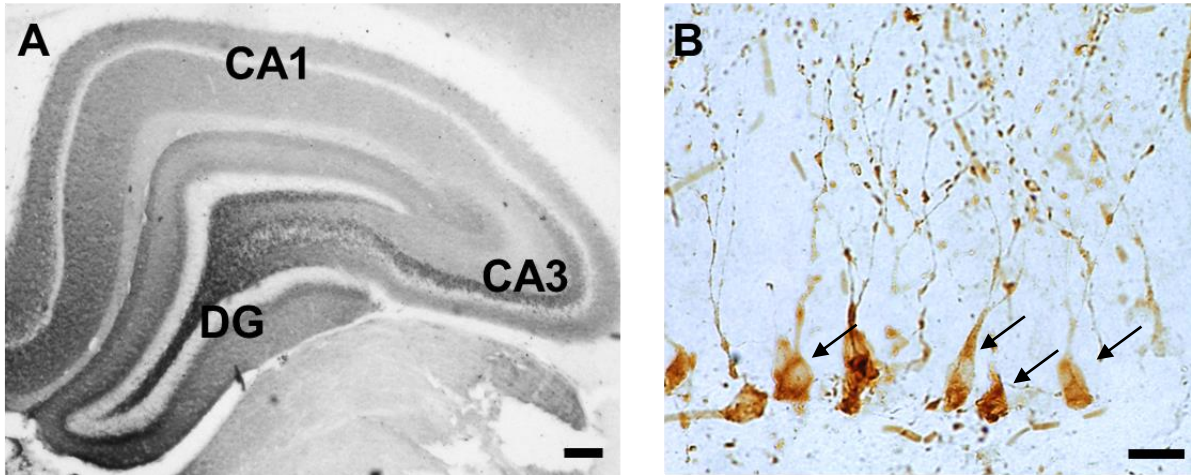


Table 1. Summary of rodent research investigating how perinatal SSRIs affect the developing hippocampus. P=postnatal day, G=gestation day, s.c.=subcutaneous, i.p.=intraperitoneal, pSSRI=perinatal SSRI, M=male, F=female.

Age studied	Sex	Species	SSRI (dose/day)	pSSRI admin days	Results	SSRI admin method	Reference
Hippocampus Serotonergic System							
P7, P21, P42, and P63	M	C57bl/6J mice	Fluoxetine (5mg/kg)	P1-21	- Fluox increases 5-HT at postnatal week 3 and 6 regardless of prenatal maternal stress. - Fluox restores 5-HIAA/5-HT in prenatally stressed offspring at postnatal week 3.	Oral administration to offspring; Prenatal restraint stress	Ishiwata et al 2005
P130	M	Long Evans rat	Citalopram (10mg/kg)	P8-21	- Citalopram decreases rate-limiting serotonin enzyme, tryptophan hydroxylase, in dorsal raphe.	s.c. injections to offspring	Maciag et al 2006
P21 and P84	M	Sprague- Dawley rat	Fluoxetine (Approximately 17mg/kg)	P2-21	- Fluox restored reduction in ventral 5-HT following prenatal DEX at postnatal week 3.	Administration via drinking water to dams; Prenatal dexamethasone (DEX)	Nagano et al 2015
P22	M/F	Sprague- Dawley rat	Fluoxetine (5mg/kg)	P1-21	- Fluox reverses effects of prenatal maternal stress 5-HT and 5-HIAA levels and altered the dopaminergic system.	Osmotic minipump to the dam; Prenatal restraint stress	Gemmel et al 2016
P27-30	M/F	Sprague- Dawley rat	Fluoxetine (10mg/kg)	G10- P21	- Fluox increases 5-HT and decreases 5-HIAA/5-HT in all offspring and reverses effects of prenatal maternal stress on 5-HT in female offspring. -Pre-gestational stress, regardless of fluoxetine, decreased 5-HT, particularly in female offspring.	Oral biscuit administration to dam; Pre-gestational maternal stress	Gemmel et al 2017
Hippocampal Plasticity							
P21	?	Sprague- Dawley rat	Fluoxetine (5mg/kg)	P14-21	- Fluox increased BrdU cells and prevented apoptosis (via TUNEL-positive cells) in the dentate gyrus of maternally separated pups.	i.p. injections to offspring; maternal separation	Lee et al 2001

P21 and P63	M	C57bl/6J mice	Fluoxetine (5mg/kg)	P1-21	- Fluox restored the reduction in dendritic spine density at postnatal week 3 and 9 and synapses density at postnatal week 9 in the CA3 region.	Oral administration to offspring; Prenatal restraint stress	Ishiwata et al 2005
P4,9,14, and 21 (female) P110 (male)	M/F	C57BL/6J mice	Fluoxetine (10 mg/kg)	P4-21	- Fluox decreased total BDNF and TrkB mRNA levels at P9 and BDNF IV, total BDNF, and TrkB mRNA levels at P14 in female pups - Fluox increased activity-dependent BDNF IV transcript levels and a slight increase in total BDNF mRNA levels, and decreased truncated TrkB level in the adult male hippocampus.	i.p. injections to offspring	Karpova et al. 2009
P35	M/F	Sprague-Dawley rat	Fluoxetine (5mg/kg)	P1-21	-Fluox reverses effects of prenatal maternal stress on cell proliferation (Ki67) and immature neurons (doublecortin) in GCL.	Osmotic minipump to the dam; Prenatal restraint stress	Rayen et al. 2011
P22	M	Wistar rats	Fluoxetine (5mg/kg)	G1-P21	- Fluox decreased global DNA methylation.	Oral gavage to dams	Toffoli et al 2014
P28	M	Sprague-Dawley rat	Fluoxetine (Approximately 17mg/kg)	P2-21	- Fluox restored reduction in BDNF in the dorsal hippocampus following prenatal DEX at postnatal week 4.	Administration via drinking water to dams; Prenatal dexamethasone treatment (DEX)	Nagano et al 2015
P17 and P24	M/F	C57bl/6J mice	Fluoxetine (Approximately 11mg/kg)	G7-P7	- Fluox decreased the number of perineuronal net-surrounded neurons at P24 in the dentate gyrus, particularly those without parvalbumin expression.	Administration via drinking water to dams	Umemori et al 2015
P90-97	M/F	Sprague-Dawley rat	Fluoxetine (5mg/kg)	P1-21	-Fluox reverses effects of prenatal maternal stress on immature neurons (doublecortin) in GCL. -In females, fluox increased new cell survival in GCL and decreased synaptophysin density (DG). -Prenatal stress decreased neurogenesis	Osmotic minipump to the dam; Prenatal restraint stress	Rayen et al. 2015
P196	M	Sprague-Dawley rat	Fluoxetine (5mg/kg)	P1-21	-Fluox decreased BDNF IV and TrkB mRNA expression. -Prenatal stress alone also decreased BDNF IV mRNA expression.	Osmotic minipump to the dam; Prenatal restraint stress	Boulle et al. 2016a
P175	F	Sprague-Dawley rat	Fluoxetine (5mg/kg)	P1-21	- Fluox tends to decrease BDNF exon IV mRNA levels and increase MeCP2-specific enrichment at this promoter.	Osmotic minipump to the dam; Prenatal restraint stress	Boulle et al. 2016b

					-Fluox increases levels of the repressive histone 3 lysine 27 tri-methylated mark at the corresponding promoter. - Prenatal stress alone also increased BDNF IV mRNA expression.		
P79	M/F	Sprague-Dawley rat	Fluoxetine (10mg/kg)	P2-23	- Fluox in the presence of CORT exposure increased dorsal immature neurons (doublecortin) in the male GCL. - Fluox and CORT decreased female dorsal immature neurons (doublecortin) in GCL.	i.p. injections to dams; s.c. corticosterone (CORT) to dams	Gobinath et al 2016
P22	M/F	Sprague-Dawley rat	Fluoxetine (5mg/kg)	P1-21	- No effect of fluox or prenatal stress on hippocampal presynaptic density.	Osmotic minipump to the dam; Prenatal restraint stress	Gemmel et al 2016
P27-30	M/F	Sprague-Dawley rat	Fluoxetine (10mg/kg)	G10-P21	- Fluox increases female presynaptic densities - Pre-gestational stress decreases male presynaptic densities and neurogenesis - Pre-gestational stress, regardless of fluoxetine, decreased presynaptic density in the dentate gyrus of male and female offspring.	Oral biscuit administration to dam; Pre-gestational maternal stress	Gemmel et al 2017

References

1. Almond P 2009 Postnatal depression: a global public health perspective. *Perspect Public Health* 129: 221-227.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19788165
2. Burke HM et al. 2005 Depression and cortisol responses to psychological stress: a meta-analysis. *Psychoneuroendocrinology* 30: 846-856. <http://www.ncbi.nlm.nih.gov/pubmed/15961250>
3. Leung BM and Kaplan BJ 2009 Perinatal depression: prevalence, risks, and the nutrition link--a review of the literature. *J Am Diet Assoc* 109: 1566-1575.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19699836
4. Pawluski J et al. 2017 The Neurobiology of Postpartum Anxiety and Depression. *Trends in Neurosciences*.
5. Oberlander TF and Zwaigenbaum L 2017 Disentangling Maternal Depression and Antidepressant Use During Pregnancy as Risks for Autism in Children. *JAMA* 317: 1533-1534.
<https://www.ncbi.nlm.nih.gov/pubmed/28418464>
6. Oberlander TF et al. 2006 Neonatal outcomes after prenatal exposure to selective serotonin reuptake inhibitor antidepressants and maternal depression using population-based linked health data. *Arch Gen Psychiatry* 63: 898-906.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16894066
7. Cooper WO et al. 2007 Increasing use of antidepressants in pregnancy. *Am J Obstet Gynecol* 196: 544 e541-545.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17547888
8. Gentile S 2005 The safety of newer antidepressants in pregnancy and breastfeeding. *Drug Saf* 28: 137-152.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15691224
9. Hayes RM et al. 2012 Maternal antidepressant use and adverse outcomes: a cohort study of 228,876 pregnancies. *Am J Obstet Gynecol* 207: 49 e41-49. <https://www.ncbi.nlm.nih.gov/pubmed/22727349>
10. Charlton RA et al. 2015 Selective serotonin reuptake inhibitor prescribing before, during and after pregnancy: a population-based study in six European regions. *BJOG* 122: 1010-1020.
<https://www.ncbi.nlm.nih.gov/pubmed/25352424>
11. Zoega H et al. 2015 Use of SSRI and SNRI Antidepressants during Pregnancy: A Population-Based Study from Denmark, Iceland, Norway and Sweden. *PLoS One* 10: e0144474.
<https://www.ncbi.nlm.nih.gov/pubmed/26657647>
12. Lupattelli A et al. 2014 Medication use in pregnancy: a cross-sectional, multinational web-based study. *BMJ Open* 4: e004365. <https://www.ncbi.nlm.nih.gov/pubmed/24534260>
13. Kim DR et al. 2014 Pharmacotherapy of postpartum depression: an update. *Expert Opin Pharmacother* 15: 1223-1234. <http://www.ncbi.nlm.nih.gov/pubmed/24773410>
14. Oberlander TF et al. 2009 Sustained neurobehavioral effects of exposure to SSRI antidepressants during development: molecular to clinical evidence. *Clin Pharmacol Ther* 86: 672-677.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19890255
15. Homberg JR et al. 2010 New perspectives on the neurodevelopmental effects of SSRIs. *Trends Pharmacol Sci* 31: 60-65.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19963284

16. Glover ME and Clinton SM 2016 Of rodents and humans: A comparative review of the neurobehavioral effects of early life SSRI exposure in preclinical and clinical research. *Int J Dev Neurosci* 51: 50-72. <https://www.ncbi.nlm.nih.gov/pubmed/27165448>
17. Gemmel M et al. 2017 Perinatal fluoxetine effects on social play, the HPA system, and hippocampal plasticity in pre-adolescent male and female rats: Interactions with pre-gestational maternal stress. *Psychoneuroendocrinology* 84: 159-171. <https://www.ncbi.nlm.nih.gov/pubmed/28735226>
18. Clements CC et al. 2015 Prenatal antidepressant exposure is associated with risk for attention-deficit hyperactivity disorder but not autism spectrum disorder in a large health system. *Mol Psychiatry* 20: 727-734. <https://www.ncbi.nlm.nih.gov/pubmed/25155880>
19. Man KK et al. 2015 Exposure to selective serotonin reuptake inhibitors during pregnancy and risk of autism spectrum disorder in children: a systematic review and meta-analysis of observational studies. *Neurosci Biobehav Rev* 49: 82-89. <http://www.ncbi.nlm.nih.gov/pubmed/25498856>
20. Oberlander TF et al. 2007 Externalizing and attentional behaviors in children of depressed mothers treated with a selective serotonin reuptake inhibitor antidepressant during pregnancy. *Arch Pediatr Adolesc Med* 161: 22-29.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17199063
21. Brown HK et al. 2017 Association Between Serotonergic Antidepressant Use During Pregnancy and Autism Spectrum Disorder in Children. *JAMA* 317: 1544-1552.
<https://www.ncbi.nlm.nih.gov/pubmed/28418480>
22. Mezzacappa A et al. 2017 Risk for Autism Spectrum Disorders According to Period of Prenatal Antidepressant Exposure: A Systematic Review and Meta-analysis. *JAMA Pediatr*.
<https://www.ncbi.nlm.nih.gov/pubmed/28418571>
23. Haim A et al. 2014 Gestational stress induces persistent depressive-like behavior and structural modifications within the postpartum nucleus accumbens. *Eur J Neurosci* 40: 3766-3773.
<http://www.ncbi.nlm.nih.gov/pubmed/25359225>
24. O'Mahony SM et al. 2006 Gestational stress leads to depressive-like behavioural and immunological changes in the rat. *Neuroimmunomodulation* 13: 82-88.
<http://www.ncbi.nlm.nih.gov/pubmed/17033197>
25. Gaspar P et al. 2003 The developmental role of serotonin: news from mouse molecular genetics. *Nat Rev Neurosci* 4: 1002-1012. <http://www.ncbi.nlm.nih.gov/pubmed/14618156>
26. Herlenius E and Lagercrantz H 2004 Development of neurotransmitter systems during critical periods. *Exp Neurol* 190 Suppl 1: S8-21. <http://www.ncbi.nlm.nih.gov/pubmed/15498537>
27. Whitaker-Azmitia PM 2001 Serotonin and brain development: role in human developmental diseases. *Brain Res Bull* 56: 479-485. <http://www.ncbi.nlm.nih.gov/pubmed/11750793>
28. Ansorge MS et al. 2008 Inhibition of serotonin but not norepinephrine transport during development produces delayed, persistent perturbations of emotional behaviors in mice. *J Neurosci* 28: 199-207.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18171937
29. Ansorge MS et al. 2004 Early-life blockade of the 5-HT transporter alters emotional behavior in adult mice. *Science* 306: 879-881.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15514160
30. Fernandez SP et al. 2016 Constitutive and Acquired Serotonin Deficiency Alters Memory and Hippocampal Synaptic Plasticity. *Neuropsychopharmacology*.
<https://www.ncbi.nlm.nih.gov/pubmed/27461084>

31. Kurzepa S and Bojanek J 1965 The 5HT level and MAO activity in rat brain during development. *Biol Neonat* 8: 216-221. <https://www.ncbi.nlm.nih.gov/pubmed/5865342>
32. Baker PC and Quay WB 1969 5-hydroxytryptamine metabolism in early embryogenesis, and the development of brain and retinal tissues. A review. *Brain Res* 12: 273-295. <https://www.ncbi.nlm.nih.gov/pubmed/4897075>
33. Kristensen JH et al. 1999 Distribution and excretion of fluoxetine and norfluoxetine in human milk. *Br J Clin Pharmacol* 48: 521-527. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10583022
34. Gemmel M et al. 2017 Perinatal selective serotonin reuptake inhibitor medication (SSRI) effects on social behaviors, neurodevelopment and the epigenome. *Neuroscience & Biobehavioral Reviews*.
35. Pawluski JL 2012 Perinatal selective serotonin reuptake inhibitor exposure: impact on brain development and neural plasticity. *Neuroendocrinology* 95: 39-46. <http://www.ncbi.nlm.nih.gov/pubmed/21893935>
36. Ishiwata H et al. 2005 Selective serotonin reuptake inhibitor treatment of early postnatal mice reverses their prenatal stress-induced brain dysfunction. *Neuroscience* 133: 893-901. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15927403
37. Gemmel M et al. under review Perinatal fluoxetine effects on social play, the HPA system, and hippocampal plasticity in pre-adolescent male and female rats: interactions with maternal stress. . *Psychoneuroendocrinology*.
38. Gemmel M et al. 2015 Developmental fluoxetine and prenatal stress effects on serotonin, dopamine, and synaptophysin density in the PFC and hippocampus of offspring at weaning. *Dev Psychobiol*. <http://www.ncbi.nlm.nih.gov/pubmed/26477449>
39. Nagano M et al. 2012 Early intervention with fluoxetine reverses abnormalities in the serotonergic system and behavior of rats exposed prenatally to dexamethasone. *Neuropharmacology* 63: 292-300. <http://www.ncbi.nlm.nih.gov/pubmed/22710353>
40. Olivier JD et al. 2013 The effects of maternal depression and maternal selective serotonin reuptake inhibitor exposure on offspring. *Front Cell Neurosci* 7: 73. <http://www.ncbi.nlm.nih.gov/pubmed/23734100>
41. Cabrera TM and Battaglia G 1994 Delayed decreases in brain 5-hydroxytryptamine_{2A/2C} receptor density and function in male rat progeny following prenatal fluoxetine. *J Pharmacol Exp Ther* 269: 637-645. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8182530
42. Sarkar A et al. 2014 Postnatal fluoxetine-evoked anxiety is prevented by concomitant 5-HT_{2A/C} receptor blockade and mimicked by postnatal 5-HT_{2A/C} receptor stimulation. *Biol Psychiatry* 76: 858-868. <https://www.ncbi.nlm.nih.gov/pubmed/24315410>
43. Huang Y et al. 2012 Pre-gestational stress reduces the ratio of 5-HIAA to 5-HT and the expression of 5-HT_{1A} receptor and serotonin transporter in the brain of foetal rat. *BMC Neurosci* 13: 22. <http://www.ncbi.nlm.nih.gov/pubmed/22373128>
44. Haring JH et al. 1993 Hippocampal serotonin levels influence the expression of S100 beta detected by immunocytochemistry. *Brain Res* 631: 119-123. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8298984
45. Whitaker-Azmitia PM et al. 1990 Stimulation of astroglial 5-HT_{1A} receptors releases the serotonergic growth factor, protein S-100, and alters astroglial morphology. *Brain Res* 528: 155-158.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=245332

46. Pawluski JL et al. 2009 Neonatal S100B protein levels after prenatal exposure to selective serotonin reuptake inhibitors. *Pediatrics* 124: e662-670. <http://www.ncbi.nlm.nih.gov/pubmed/19786426>

47. Bhattacharyya A et al. 1992 S100 is present in developing chicken neurons and Schwann cells and promotes motor neuron survival in vivo. *J Neurobiol* 23: 451-466.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1634890

48. Gonzalez-Martinez T et al. 2003 S-100 proteins in the human peripheral nervous system. *Microsc Res Tech* 60: 633-638.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12645010

49. Selinfreund RH et al. 1991 Neurotrophic protein S100 beta stimulates glial cell proliferation. *Proc Natl Acad Sci U S A* 88: 3554-3558. <https://www.ncbi.nlm.nih.gov/pubmed/1902567>

50. Brummelte S et al. 2013 Antidepressant use during pregnancy and serotonin transporter genotype (SLC6A4) affect newborn serum reelin levels. *Dev Psychobiol* 55: 518-529.

<http://www.ncbi.nlm.nih.gov/pubmed/22692766>

51. Podrebarac SK et al. 2016 Antenatal exposure to antidepressants is associated with altered brain development in very preterm-born neonates. *Neuroscience*.

<https://www.ncbi.nlm.nih.gov/pubmed/27890829>

52. Eriksson PS et al. 1998 Neurogenesis in the adult human hippocampus. *Nat Med* 4: 1313-1317.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9809557

53. Pawluski JL et al. 2009 Effects of steroid hormones on neurogenesis in the hippocampus of the adult female rodent during the estrous cycle, pregnancy, lactation and aging. *Front Neuroendocrinol* 30: 343-357. <http://www.ncbi.nlm.nih.gov/pubmed/19361542>

54. Hammels C et al. 2015 Differential susceptibility to chronic social defeat stress relates to the number of Dnmt3a-immunoreactive neurons in the hippocampal dentate gyrus. *Psychoneuroendocrinology* 51: 547-556. <http://www.ncbi.nlm.nih.gov/pubmed/25445743>

55. Dalla C et al. 2009 Stressful experience has opposite effects on dendritic spines in the hippocampus of cycling versus masculinized females. *Neurosci Lett* 449: 52-56.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18952150

56. Leuner B and Gould E 2010 Structural plasticity and hippocampal function. *Annu Rev Psychol* 61: 111-140, C111-113.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19575621

57. Djavadian RL 2004 Serotonin and neurogenesis in the hippocampal dentate gyrus of adult mammals. *Acta Neurobiol Exp (Wars)* 64: 189-200.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15366252

58. Altman J 1962 Are new neurons formed in the brains of adult mammals? *Science* 135: 1127-1128.

<https://www.ncbi.nlm.nih.gov/pubmed/13860748>

59. Altman J and Das GD 1967 Postnatal neurogenesis in the guinea-pig. *Nature* 214: 1098-1101.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=6053066

60. Boulle F et al. 2012 Epigenetic regulation of the BDNF gene: implications for psychiatric disorders. *Mol Psychiatry* 17: 584-596. <https://www.ncbi.nlm.nih.gov/pubmed/21894152>

61. Castren E and Rantamaki T 2010 The role of BDNF and its receptors in depression and antidepressant drug action: Reactivation of developmental plasticity. *Dev Neurobiol* 70: 289-297.
<https://www.ncbi.nlm.nih.gov/pubmed/20186711>
62. Karpova NN et al. 2009 Long-lasting behavioural and molecular alterations induced by early postnatal fluoxetine exposure are restored by chronic fluoxetine treatment in adult mice. *Eur Neuropsychopharmacol* 19: 97-108.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18973993
63. Toffoli LV et al. 2014 Maternal exposure to fluoxetine during gestation and lactation affects the DNA methylation programming of rat's offspring: modulation by folic acid supplementation. *Behav Brain Res* 265: 142-147. <http://www.ncbi.nlm.nih.gov/pubmed/24583191>
64. Molteni R et al. 2010 Reduced function of the serotonin transporter is associated with decreased expression of BDNF in rodents as well as in humans. *Neurobiol Dis* 37: 747-755.
<https://www.ncbi.nlm.nih.gov/pubmed/20034565>
65. Boulle F et al. 2016 Developmental fluoxetine exposure increases behavioral despair and alters epigenetic regulation of the hippocampal BDNF gene in adult female offspring. *Horm Behav* 80: 47-57.
<https://www.ncbi.nlm.nih.gov/pubmed/26844865>
66. Boulle F et al. 2016 Prenatal stress and early-life exposure to fluoxetine have enduring effects on anxiety and hippocampal BDNF gene expression in adult male offspring. *Dev Psychobiol* 58: 427-438.
<http://www.ncbi.nlm.nih.gov/pubmed/26608001>
67. Rayen I et al. 2011 Fluoxetine during development reverses the effects of prenatal stress on depressive-like behavior and hippocampal neurogenesis in adolescence. *PLoS One* 6: e24003.
<http://www.ncbi.nlm.nih.gov/pubmed/21912658>
68. Rayen I et al. 2015 Developmental exposure to SSRIs, in addition to maternal stress, has long-term sex-dependent effects on hippocampal plasticity. *Psychopharmacology (Berl)* 232: 1231-1244.
<http://www.ncbi.nlm.nih.gov/pubmed/25304865>
69. Lee HJ et al. 2001 Fluoxetine enhances cell proliferation and prevents apoptosis in dentate gyrus of maternally separated rats. *Mol Psychiatry* 6: 610, 725-618.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11673802
70. Gobinath AR et al. 2016 Maternal postpartum corticosterone and fluoxetine differentially affect adult male and female offspring on anxiety-like behavior, stress reactivity, and hippocampal neurogenesis. *Neuropharmacology* 101: 165-178. <https://www.ncbi.nlm.nih.gov/pubmed/26391064>
71. Umemori J et al. 2015 Distinct effects of perinatal exposure to fluoxetine or methylmercury on parvalbumin and perineuronal nets, the markers of critical periods in brain development. *Int J Dev Neurosci* 44: 55-64. <https://www.ncbi.nlm.nih.gov/pubmed/25997908>
72. Glover ME et al. 2015 Early-life exposure to the SSRI paroxetine exacerbates depression-like behavior in anxiety/depression-prone rats. *Neuroscience* 284: 775-797.
<https://www.ncbi.nlm.nih.gov/pubmed/25451292>
73. Galea LA et al. 2006 Gonadal hormone modulation of hippocampal neurogenesis in the adult. *Hippocampus* 16: 225-232. <http://www.ncbi.nlm.nih.gov/pubmed/16411182>
74. Tabori NE et al. 2005 Ultrastructural evidence that androgen receptors are located at extranuclear sites in the rat hippocampal formation. *Neuroscience* 130: 151-163.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15561432
75. Weiland NG et al. 1997 Distribution and hormone regulation of estrogen receptor immunoreactive cells in the hippocampus of male and female rats. *J Comp Neurol* 388: 603-612.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9388019

76. Dohler KD et al. 1991 Influence of neurotransmitters on sexual differentiation of brain structure and function. *Exp Clin Endocrinol* 98: 99-109.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1685710

77. Jarzab B and Dohler KD 1984 Serotonergic influences on sexual differentiation of the rat brain. *Prog Brain Res* 61: 119-126.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=6241317

78. Wilson CA et al. 1986 The effect of neonatal manipulation of hypothalamic serotonin levels on sexual activity in the adult rat. *Pharmacol Biochem Behav* 24: 1175-1183.

<http://www.ncbi.nlm.nih.gov/pubmed/2425376>

79. Rayen I et al. 2013 Developmental fluoxetine exposure and prenatal stress alter sexual differentiation of the brain and reproductive behavior in male rat offspring. *Psychoneuroendocrinology*.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=23399049

80. Maccari S et al. 2014 The consequences of early-life adversity: neurobiological, behavioural and epigenetic adaptations. *J Neuroendocrinol* 26: 707-723.

<http://www.ncbi.nlm.nih.gov/pubmed/25039443>

81. Mirescu C and Gould E 2006 Stress and adult neurogenesis. *Hippocampus* 16: 233-238.

<https://www.ncbi.nlm.nih.gov/pubmed/16411244>

82. Lucassen PJ et al. 2009 Prenatal stress reduces postnatal neurogenesis in rats selectively bred for high, but not low, anxiety: possible key role of placental 11beta-hydroxysteroid dehydrogenase type 2. *Eur J Neurosci* 29: 97-103.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19032587

83. Laurent L et al. 2017 Human placenta expresses both peripheral and neuronal isoform of tryptophan hydroxylase. *Biochimie* 140: 159-165. <https://www.ncbi.nlm.nih.gov/pubmed/28751217>

84. Muller CL et al. 2017 Impact of Maternal Serotonin Transporter Genotype on Placental Serotonin, Fetal Forebrain Serotonin, and Neurodevelopment. *Neuropsychopharmacology* 42: 427-436.

<https://www.ncbi.nlm.nih.gov/pubmed/27550733>

85. Bonnin A and Levitt P 2011 Fetal, maternal, and placental sources of serotonin and new implications for developmental programming of the brain. *Neuroscience* 197: 1-7.

<https://www.ncbi.nlm.nih.gov/pubmed/22001683>

86. Rayen I et al. 2014 Developmental fluoxetine exposure facilitates sexual behavior in female offspring. *Psychopharmacology (Berl)* 231: 123-133. <http://www.ncbi.nlm.nih.gov/pubmed/23900642>

87. Pawluski JL et al. 2012 Developmental fluoxetine exposure differentially alters central and peripheral measures of the HPA system in adolescent male and female offspring. *Neuroscience* 220: 131-141.

<http://www.ncbi.nlm.nih.gov/pubmed/22728102>

88. Pawluski JL et al. 2012 Prenatal SSRI exposure alters neonatal corticosteroid binding globulin, infant cortisol levels, and emerging HPA function. *Psychoneuroendocrinology* 37: 1019-1028.

<http://www.ncbi.nlm.nih.gov/pubmed/22177580>

89. Bodnar LM and Wisner KL 2005 Nutrition and depression: implications for improving mental health among childbearing-aged women. *Biol Psychiatry* 58: 679-685.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16040007

90. Swain JE et al. 2017 Parent-child intervention decreases stress and increases maternal brain activity and connectivity during own baby-cry: An exploratory study. *Dev Psychopathol* 29: 535-553. <https://www.ncbi.nlm.nih.gov/pubmed/28401845>
91. Angelotta C and Wisner KL 2017 Treating Depression during Pregnancy: Are We Asking the Right Questions? *Birth Defects Res* 109: 879-887. <https://www.ncbi.nlm.nih.gov/pubmed/28714606>