Fetal Hippocampal Development Affects Prenatal Attachment Representations

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Abstract: Memories of prenatal relational experience leave physical and chemical imprints on the brain and nervous system of an unborn child that influence attachment tendencies and behaviors. Attachment representations develop *in utero* as an unborn child thinks, feels, learns, behaves, and remembers according to environmental stimuli that are activated by interaction with maternal transmissions during critical gestational periods. Research on fetal hippocampal development has revealed that the mechanisms required for mental representations of attachment relationships to develop are present and functioning during the fetal period by the 13th week of gestation. The findings in this literature review support that a child begins to formulate predictions about the relationship with his or her mother during the prenatal period.

Keywords: fetal hippocampal development, mental representations, prenatal attachment, literature review

Advanced technologies that involve *in vivo* approaches are now being utilized to analyze and observe fetal brain development, fetal brain structure and functioning, fetal sensory perception, and fetal memory consolidation (Ammaniti & Gallese, 2014; Bonilla-Musoles et al., 2009; Hata et al., 2016; Rousseau et al., 2016; Schopf et al., 2016). Molecular technologies can now detect pivotal points of gestation when a fetus is motivated to switch on certain genes related to enhancing the maternal-fetal attachment bond (Ainsworth, 2017). Findings within studies that have utilized these technologies support that social learning, self-awareness, and the capacity for explicit memory consolidation and

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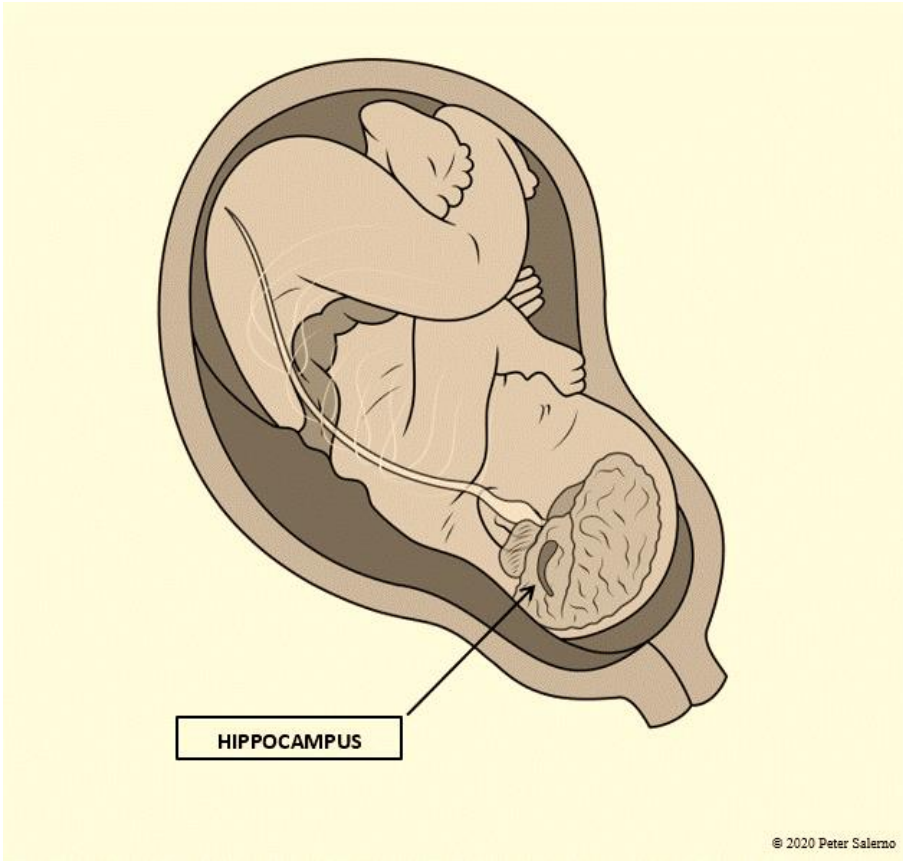
recollection are evident capacities of the second and third trimester fetus (Irmak, 2016; Krueger & Garvan, 2014; Pino, 2016). Moreover, maternal-fetal relationship quality highly predicts how a fetus consolidates memories of his or her mother; the encoding of these memories can contribute to the development of a mental model of the maternal-fetal attachment relationship that can persist in the child's neural networks across the lifespan (Kinsella & Monk, 2009).

Studies conducted utilizing four-dimensional ultrasound imaging (4D) augmented by HD Live enhancement, fetal brain analysis using magnetic resonance imaging (MRI), fetal functional magnetic resonance imaging (fMRI), and fetal biomagnetometry have demonstrated that a fetus learns about his or her mother and can consolidate intersubjective experiences during the fetal period (Ammaniti & Gallese, 2014; Castiello et al., 2010; Gustafson & Popescu, 2016; Hata et al., 2016; Rousseau et al., 2016; Schopf et al., 2016). These capacities serve the purpose of ensuring survival through the establishment of an explicit attachment bond and are largely made possible due to fetal hippocampal development (Girardeau et al., 2017; Glenn, 2009; Irmak, 2016; Joseph, 2017; Prayer et al., 2006; Rados et al., 2006). The hippocampus is the primary brain structure involved in explicit or declarative memory, self-awareness, and the connection of mental representations to emotions (Girardeau et al., 2017; Irmak, 2016; Joseph, 2017; Siegel, 2012). Recent observational studies have revealed that the hippocampus appears at the eighth week of gestation in the human embryo and is anatomically fully developed in a human fetus by 13 weeks gestational age (Ge et al., 2015; Huang, 2010; Irmak, 2016; Kostovic & Vasung, 2009). This is evidenced by the identification and observation of hippocampal sulcus, hippocampal primordial, and adult-type hippocampus through the use of fetal MRI (Glenn, 2009; Irmak, 2016; Prayer et al., 2006; Rados et al., 2006). The fully-formed hippocampus at 13 weeks gestational age allows for the capacity to form, store, and retrieve memories and to associate these memories with mental representations that connect to other emotional regions in the brain (Bennett et al., 2015; Cotiga, 2013; Irmak, 2016; Levine, 2015). With a fully-formed hippocampus, the fetus has the capacity to utilize episodic and semantic memory, and through cognitive, emotional, and sensory experience, to recall memories of his or her mother as well as recall interactive qualities of the relational bond with his or her mother during gestation (Cotiga, 2013; Knierim, 2015; Parncutt, 2018; Pino, 2016; Platt, 2011; Reese, 2018; van Manen, 2018). The fully-formed hippocampus in the second trimester fetus is presented in Figure 1.

Figure 1. Fully formed hippocampus at 13 weeks of gestation. The hippocampus appears at the eighth week of gestation and is fully developed in a human fetus at 13 weeks gestational age. Identified and observed through the use of fetal magnetic resonance imaging (MRI).



One critical feature of the attachment system is the development of internal working models (Johnson, 2019; Levenson, 2015; Spinelli et al., 2017; Tucci et al., 2019). Bowlby (1969, 1988) used the concept of internal working models to refer to mental representations of attachment relationships. An internal working model serves as an expectation system for a child to assist in predicting continuity of relational experience and assurance of interactive relational outcomes (Crowell et al., 2018; Fisher, 2017; Groh et al., 2017; Johnson, 2019). Attachment studies have demonstrated that a child's internal working models are mainly influenced by his or her mother's internal working models (Berlin et al., 2018).

Historically, attachment theorists have posited that internal working models develop and are encoded in the infant brain from birth until around 12 months of age (Bretherton & Munholland, 2018). However, Bowlby himself (1969, 1988) did not limit the development of internal working models to mental representations of attachment relationships after birth. He submitted that internal working models are developmental constructs which can progress in any organism that possesses the capacity to organize and store information over time. Due to fetal hippocampal development, the capacity to organize and store information is possible as early as 13 weeks gestational age in a human fetus (Ge et al., 2015; Huang, 2010; Irmak, 2016; Kostovic & Vasung, 2009). Therefore, the development of mental representations begins much sooner than infancy.

Mental representations are neurochemical imprints of experience (Canas, 2015; Fisher, 2017; Kitamura et al., 2017; Levine, 2015; Levitin, 2006; Liu et al., 2012; Richetto & Riva, 2014; Weinstein, 2016). The human auditory system is a useful example to explain how mental representations are formed and how they are necessary features of prenatal development. Auditory sensory experience is a mental representation produced by the brain in response to the vibration of air molecules (Levitin, 2006). During the second and third trimesters of gestation, the human fetus begins to receive signals to the brain that are interpreted as sound, and the fetus can remember these sounds (Andre et al., 2018; Kisilevsky, 2009; Partanen et al., 2013). Prenatal studies have demonstrated that changes in fetal heart rate and nervous system activity occur as early as 19 weeks gestational age when the fetus recalls something familiar, such as the mother's voice, a song, or other environmental sounds (Andre et al., 2018; de Lima Lemos et al., 2011; Muenssinger & Preissl, 2016). At 28 weeks gestational age, when the auditory stimulus is maintained for a number of weeks, then taken away, and then reintroduced weeks later, a decrease in fetal heart rate occurs as well as a reduction in sympathetic nervous system activity (Andre et al., 2018; Graven & Browne, 2008). These findings indicate that the stimulus was stored in the fetal brain as a semantic and episodic memory and was therefore consolidated and remembered by the fetus (Andre et al., 2018; Graven & Browne, 2008).

A mental representation of an auditory experience is possible because experiences are organized in time through the hippocampal system (Eichenbaum, 2017). Fetal recognition of sound and the capacity to store memories of sounds detected *in utero* is particularly significant because the human auditory system requires stimulation from exogenous sound sources beginning from 28 to 40 weeks gestational age in order to develop properly and function optimally after birth (Graven & Browne, 2008). The human auditory system develops based on experience with voices, music,

and other environmental sounds *in utero*, and fetal learning of specific sounds, as well as the capacity to differentiate them from unlearned sounds after birth, has been empirically validated (Graven & Browne, 2008). Not only does this research show that fetal episodic and semantic memory recall of sensory stimuli such as sound are possible; it also supports that fetal episodic and semantic memory recall are required for optimal development of sensory systems.

Maternal social support significantly influences physical and mental health in pregnant women and impacts prenatal attachment (Gallegos et al., 2017; Nomaguchi & Milkie, 2018). An expectant mother's interaction with her social support system can positively and negatively impact attachment to her unborn child (Gallegos et al., 2017; Freeman & Brewer, 2013; Glover & Capron, 2017; Nomaguchi & Milkie, 2018; Stapleton & Bradbury, 2012; Stapleton et al., 2012). Social support during pregnancy has been shown to increase the physiological and psychological health of both mother and unborn child (McKee et al., 2017). It has been suggested within the research on prenatal attachment that psychoeducation regarding the impact of maternal social support on the unborn child should be discussed with expectant mothers during the prenatal care process (Glembocki & Schuiling, 2017).

Maternal secure attachment is the most significant preventative against maladaptive mental representations in unborn children (Chrzan-Detkos & Lockiewicz, 2015; Johnson, 2013, 2019; McMahon, et al., 2016; Mesman et al., 2018; Pisoni et al., 2014; van Bakel et al., 2013). Attachment characteristics and behaviors can be adaptively imprinted onto the brain and nervous system of a child *in utero* through attachment-oriented interventions that increase emotional security in expectant mothers (Brassard & Johnson, 2018; Cortizo, 2019; Johnson, 2019; Slade, 2018; Wallin, 2015). These attachment-based interventions can modify the expression of genes involved in releasing stress hormones that perpetuate insecure attachment characteristics and switch on genes involved in neurotransmission that contribute to attachment security (Johnson, 2013, 2019; Lyons-Ruth & Jacobvitz, 2018; McClelland et al., 2018). If a secure mental representation is cultivated for an expectant mother through the therapeutic process, this model can be drawn upon, internalized, and remembered by her unborn child during gestation (Neuenschwander & Oberlander, 2018; Weinstein, 2016).

Cultivating secure attachment in pregnant women directly promotes secure attachment in offspring (Farley et al., 2019; Havighurst & Kehoe, 2018). Promoting a secure bond between a mother and her unborn child is essential for secure attachment outcomes, and clinicians can assist in this process by establishing a secure attachment bond with the mother as well as by recognizing the memory capacities of a second and third trimester

fetus (O'Connor et al., 2019; Westerling et al., 2019). The more securely attached an expectant mother becomes to a safe and competent therapist who is present, attuned, and self-regulated (Dana, 2018; Johnson, 2019), the more capable the mother will be at becoming a secure base for her unborn child (La Marca-Ghaemmaghami & Ehlert, 2015; Weinstein, 2016). Maternal emotion regulation, attunement, present awareness, and adaptive coping capacities increase as a result of the development of a secure attachment to a therapist (Crnic & Ross, 2018; McCreary et al., 2016; Porges, 2017). These relational factors are modeled by the therapist throughout the therapeutic process (Crnic & Ross, 2018; McCreary et al., 2016; Porges, 2017). As the mother develops adaptive attachment tendencies in therapy, emotion regulation capacities of her unborn child may imprint and be recalled across the lifespan (Crnic & Ross, 2018; McCreary et al., 2016; Porges, 2017).

This literature review indicates major implications for both the field of psychology and the practice and application of psychotherapy. The data collected in this review calls for advancements in research on prenatal aspects of attachment theory. While much emphasis is placed on the infancy period in attachment research, there is insufficient data regarding the impact of the prenatal period on attachment, which shapes the socioemotional life of a human being in profound ways. This article revealed that attachment imprints occur long before birth; therefore, there is a need to study and treat the intrauterine environment with great care in order to prevent maladaptive attachment and cultivate secure attachment in unborn children. Further research within the fields of developmental psychology, developmental programming, interpersonal neurobiology, evolutionary psychology, epigenetics, and prenatal studies may contribute information regarding various anomalies in attachment formation, offering explanations for how seemingly resourceful and adaptive social environments can still produce maladaptive attachment in many children and adults. The explanations for these anomalies may be connected to the often-overlooked and understudied intrauterine environment, the memory capacity of the fetus due to hippocampal development at 13 weeks gestational age, and its impact on attachment.

Interventions that are indicated during pregnancy to promote adaptive fetal memory consolidation and sensory perception include individual psychotherapy for expectant mothers, psychoeducation, mentalization practices, and emotional focused therapy for expectant couples (Berlin et al., 2018; Bhamani, 2017; Brassard & Johnson, 2018; Cortizo, 2019; Dalton et al., 2013; Fonagy et al., 2018; Johnson, 2013; Johnson, 2013, 2019; Markin, 2013, 2018; Mikic & Terradas, 2018; O'Connor et al., 2019; Slade, 2018; Wallin, 2015; Westerling et al., 2019). These interventions can positively impact the biopsychosocial health of the

expectant mother which directly influences fetal memory relationship (Barzeger et al., 2014; Drake, 2014; Kim et al., 2015; Scheinost et al., 2017).

This literature review examined fetal hippocampal development and its impact on prenatal attachment representations. The hippocampus makes the capacity to develop and store mental representations possible long before birth. In order for mental representations to form, the capacities for learning and storing memories must be operative. The hippocampus is the limbic structure that plays the most significant role in converting learned information and socioemotional experience to long term memories that can be recalled explicitly. Because observational research has shown that the hippocampus is fully formed and operative at 13 weeks gestational age, the mechanisms involved in the development and storage of internal working models are functioning in human beings by the second trimester. The hippocampus is the brain's center for self-awareness, emotional experience, and explicit or declarative memory. The findings in this literature review support the capacity for fetuses to develop mental representations of the relationship between themselves and their mothers during the prenatal period and is made possible largely due to the fetal brain containing an adult-type hippocampus by 13 weeks gestational age.

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