Chapter 2
Understanding the Development of the Central Nervous System and Its Relationship to Clinical Practice

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Learning Objectives

1. To understand the basic neuroanatomy of the brain.
2. To understand the development of the brain and how it affects later functioning.
3. To understand the relation of early experience and culture to the development of the brain.
4. To relate basic knowledge of the central nervous system to clinical practice.

Overview

The goal of this chapter is to review the basic development of the central nervous system and to relate this development to clinical practice. The chapter will begin with a basic neuroanatomy of the brain starting with a discussion of the structure and function of the four lobes. In addition, this structure and function will be discussed as it relates to stages within a neurotypical child's development. Multicultural and ethnic differences will be discussed as they relate to neuroanatomy. Finally, a foundation for later chapters on errors in neurodevelopment will be provided to assist the clinical, school, and counseling psychologist in understanding why this neurodevelopment is crucial for the child's adjustment.

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Basic Brain Anatomy

To understand the development of the central nervous system (CNS), it is first important to have a basic knowledge of brain anatomy. The brain is composed of two hemispheres that include four lobes (frontal, temporal, occipital, and parietal), the cerebellum, and the brain stem. In addition, it also includes the basal ganglia, limbic system, and ventricles. The neurons that make up the brain include the nuclei (the gray matter on the outside of the brain) and the axons (the white matter internal to the brain). The brain is surrounded and cushioned by the meninges and cerebrospinal fluid (CSF). There are three meninges: pia mater (the most interior and contains small blood vessels), arachnoid (a spiderlike web between the pia and dura mater), and the dura mater (a tough exterior meninge which attaches to the bones covering the cranium and has the blood vessels that nourish the brain). The cerebrospinal fluid serves to protect against injury by providing a cushion as well as diffusing materials into and away from the brain and lies within the ventricles as well as within the subdural space between the dura mater and arachnoid meninges. Infections can attack the meninges and are referred to as meningitis. These infections have serious consequences for the developing brain particularly with the first year of life and can result in death or intellectual disability, hydrocephalus, seizures, deafness, and hyperactivity (Swaiman & Ashwal, 2017). Hydrocephalus is generally remediated through a shunt being placed in the ventricles and draining to the stomach. Hydrocephaly can range from mild to severe with the age of the child at the time of the shunt being placed as well as other medical conditions being present affecting the level of difficulty (Fletcher et al., 2000).

Ventricles The four ventricles are cavities that are filled with CSF. The largest ventricles are the lateral ventricles that are in the forebrain of the cortex. The third ventricle is connected to the lateral ventricles and in the deep portion of the brain in the diencephalon. In turn the fourth ventricle is connected to the brain stem and drains into the spinal cord.

Brain Stem The brain stem includes five areas: fourth ventricle, medulla oblongata, pons, midbrain, and diencephalon (see Fig. 2.1). The medulla oblongata is directly connected to the spinal cord. Sensory and motor nuclei from the cranial nerves are located here. As you may recall, the right side of the body is controlled by the left hemisphere and the left side of the body by the right. The medulla is where these pathways cross. This is true for auditory, visual, kinesthetic, and motor systems.

The reticular activating system (RAS) runs through the medulla and plays an important role in arousal as well as in maintaining consciousness and attention. It receives input from most sensory systems as well as connects to all levels of the CNS. The raphe system that secretes serotonin (an important neurotransmitter) runs through the medulla as well as the pons and midbrain sections. This region also contains the locus ceruleus which produces 70 percent of norepinephrine in the

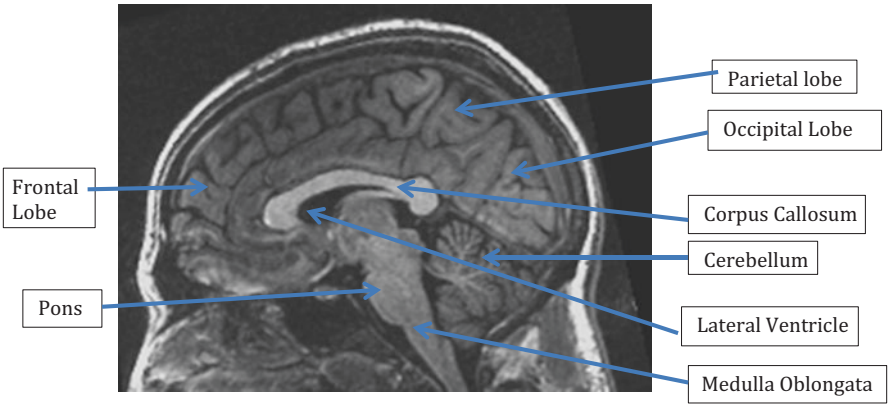

Fig. 2.1 Sagittal view of the brain showing the major structures

brain and modulates other neurotransmitters (Carlson & Birkett, 2017). Norepinephrine plays an important role in vigilance, while serotonin plays a role in mood, attachment, and aggression to name a few (Pliszka, 2016). The RAS projects to the limbic system and is affected by these neurotransmitters.

The pons is between the medulla and the midbrain and lies above the cerebellum and serves as a bridge between the hemispheres. Major sensory and motor pathways course through this area from the spinal cord to the cortex. The pons works in concert with the cerebellum and receives input from the motor cortex modulating movements (Brodal, 2016). Input from the limbic system also occurs at the level of the pons and appears to influence emotional and motivational factors on motor activity (Brodal, 2016).

The midbrain serves as a major relay for sensory-motor fibers. The midbrain includes the superior colliculi that are important for vision orientation and the inferior colliculi that are involved in the integration of auditory and kinesthetic input. Several cranial nerves also traverse through the midbrain particularly those for eye movement and sensory movement of the face.

The diencephalon is the most superior region of the brain stem and contains the major relax center for all sensory systems except smell. It includes the thalamus, hypothalamus, pituitary gland, internal capsule, the third ventricle, and the optic nerve (Semrud-Clikeman & Ellison, 2009). The thalamus is a crucial structure receiving input from several sensory sources including the visual, auditory, pain, pressure, touch, and temperature. The hypothalamus, which lies anterior and below the thalamus, is important for the autonomic nervous system which controls eating, sexual function/dysfunction, drinking, sleeping, temperature, rage, and violence as well as motivational aspects of behavior. The pituitary gland also is in this region and responds to hypothalamic directions in secreting hormones (cortisol, etc.) that regulate bodily functions. The hypothalamus and pituitary gland along with the adrenal gland above the kidney make up the hypothalamic-pituitary-adrenal (HPA) axis. This system is influenced by serotonin and activates during times of stress

making it difficult for the child to respond to changing situations (Pliszka, 2016; Puig et al., 2013). It can also change brain structure in young children due to stress experienced during important developmental times—this effect will be discussed later in the chapter.

Finally, the internal capsule is like a highway where fibers connect the cortex to lower brain regions. In addition, major fibers connect the frontal lobes to the thalamus and then to the pons. The optic nerve also converges in the diencephalon and forms the optic chiasm.

Cerebellum The cerebellum (also referred to as the hindbrain) connects to the midbrain, pons, and medulla. It receives sensory information about where the body is in space and the position of the limbs. It also receives input from the semicircular canals in the ear concerning orientation and balance. It works without conscious awareness for smooth and complex motor activity. Injury to the cerebellum can cause problems with movement (dystaxia) and speech (dysarthria), nystagmus (blurred vision and dizziness), and hypotonia (low muscle tone; Swaiman & Ashwal, 2017).

The Cortex

The cortex is the highest functional division of the brain and makes up about 80 percent of the human brain. It is comprised of two hemispheres that have anatomical as well as functional differences. The right and left hemispheres differ in terms of the efficiency in processing certain tasks with the left hemisphere being more efficient in language and sequential thinking and the right in wholistic processing. The right hemisphere is more adept at processing novel information, while the left hemisphere works more efficiently with pre-existing learning (Semrud-Clikeman & Ellison, 2009). Gender differences are present with women showing less lateralization then men and men showing stronger visual-spatial reasoning skills (Semrud-Clikeman & Fine, 2009).

There are large bundles of myelinated fibers that connect the various regions of the cortex. The two hemispheres are connected through the corpus callosum (large white matter fibers) as well as smaller pathways connecting the temporal lobes (anterior commissure) and parietal region (posterior commissure). There are also long pathways that connect the frontal lobes to the occipital lobes via the parietal lobes (superior longitudinal fasciculus) and the frontal lobes to the temporal lobes (inferior longitudinal fasciculus).

Frontal Lobes The frontal lobes are the most sophisticated part of the brain and are important for motor as well as reasoning, planning, and monitoring of behavior. They mature the slowest of all of the lobes and continue developing into the mid-twenties. There are many connections between the frontal lobes and all parts of the brain and particularly with the limbic system that is involved in emotion and motivation. Damage to this regions can cause problems with executive function, behav-

ioral/emotional control, and impaired judgment (Lezak et al., 2004). Connections from the prefrontal region of the brain allow for the individual to compare past and present experiences as well as to learn from experience. Consequently damage to this region (often seen in traumatic brain injury and concussions) results in impaired judgment, poor insight, and often impulsive behavior (Gazzaniga et at., 2013).

Parietal Lobes The parietal lobes play an important role in the perception of tactile and sensory information. They are important in recognizing the source, quality, and severity of pain, discrimination of light pressure and vibration, proprioception, and kinesthetic sense. The parietal lobes also integrate complex sensory information and allow for analysis of the information such as visual-motor integration.

Occipital Lobes The occipital lobes are in the posterior portion of the brain and are important for visual information and interpretation. The functions are important for complex visual perception. In addition, the current perception is paired with past learning for interpretation of meaning as well as recognition and appreciation of what is being seen. Damage to this region can result in problems with recognizing objects, faces, and drawings (Gazzaniga et al., 2013).

Limbic System The limbic system is a collection of structures deep in the cortex and includes the hippocampus, amygdala, septum, and cingulate gyrus (Carlson & Birkett, 2017). It is an important system that assists in formulating an emotional response to fearsome or threatening situations, monitoring sexual response, remembering recent and past events, and responding to need states (Pliszka, 2016). The cingulate gyrus has been associated with error checking and self-monitoring (Semrud-Clikeman et al., 2006), while feelings of anxiety, rage, and fear are associated with the amygdala (Semrud-Clikeman & Ellison, 2009). The hippocampus is crucial for learning and memory with the emotional tone of memories provided by interaction with the amygdala.

Basal Ganglia The basal ganglia are a collection of gray matter structures within the cerebral hemispheres and include the caudate, putamen, and globus pallidus. This structure connects to the cortex and the thalamus as well as to the brain stem. Serotonin pathways from the raphe nuclei in the brain stem connect to the basal ganglia and inhibit motor and emotional reactions (Gazzaniga et al., 2013). The basal ganglia (particularly the caudate) have been implicated in attention deficit hyperactivity disorder (Castellanos & Proal, 2012; Semrud-Clikeman et al., 2006).

The Developing Brain

The previous section provides a brief overview of the structural areas of the brain and is important for understanding the infant brain that changes with experience and development. The fetal brain grows at an astonishing rate prior to birth with

estimates of 250,000 brain cells forming each minute through mitosis (Nyardi et al., 2013). The fastest brain growth is between 25 and 40 weeks of gestation (Gazzaniga et al., 2013). The human brain also grows in predictable stages beginning with the neural tube at 25 days of gestation through birth. The following sections will discuss the various stages of development throughout gestation and into early childhood.

Neural Tube Formation The neural tube forms approximately 2 weeks within conception and is completed around 1 month of gestation. It is the foundation for the brain and spinal cord. The neural plate is formed and looks like the shape of a keyhole with the broad end at the anterior portion of the plate. Neurulation is a complex process where the cells in the neural plate give rise to the neural tube and later the CNS. There are three primary layers in the early embryo—ectoderm (proximal layer), mesoderm (middle layer), and endoderm (distal layer). The endoderm serves as the genesis for the gut and digestive organs, while the mesoderm is the foundation for the circulatory system. We are most concerned with the ectodermal cells that become the CNS. The ectodermal cells that lie ventrally to the neural plate form the neural crest. The neural crest becomes the peripheral nervous system, while the neural tube (the most central part of the neural plate) becomes the CNS (Gilbert, 2000) (Fig. 2.2). Illustration done by Richard Magnusson.

By day 23 the neural tube is formed with the anterior portion becoming the brain and the posterior portion the spinal cord. For a video as to this process, please access http://www.lsic.ucla.edu/classes/lifesci/central/ps107/lectures/ns-slide_2.html. The neural tube folds over with the most anterior portion becoming the forebrain, the hypothalamus and thalamus and interbrain, then the midbrain, and finally the spinal cord (Squire et al., 2008).

When the neural tube fails to close in the anterior section, the child's brain will not be encased in the skull and an encephalocele will form. An encephalocele is a sac-like projection of the brain and meninges through the skull frequently at the back of the head. These children generally do not survive. If the neural tube does not close at the caudal portion of the tube, spina bifida is present. There are levels of spina bifida that are determined by how much of the spinal cord is affected. The most common and mildest form shows very few clinical signs and generally looks like a dimple, or hairy patch on the back above the buttocks. It is not generally discovered without an X-ray. The more severe form is the meningocele where fluid leaks out of the spine and the skin bulges out. Generally there are no other clinical symptoms. The most rare and severe form is the myelomeningocele and is the common understanding of spina bifida. In this case the spinal nerves are out of the spinal canal with resulting damage ranging from lack of feeling to paralysis. The skin is open in this case, and the sac-like projection is unprotected from infection, etc.

Spina bifida is a common severe birth defect with a prevalence of 1 per 1000 in the USA. Rates are higher in Hispanics and whites of European descent and lower in Ashkenazi Jews, Asians, and African Americans. Mothers with diabetes or seizure disorders have a higher rate of spina bifida in children. The prognosis for children with spina bifida is much better in recent years with improved surgical techniques and early diagnosis leading to corrective surgery during pregnancy.

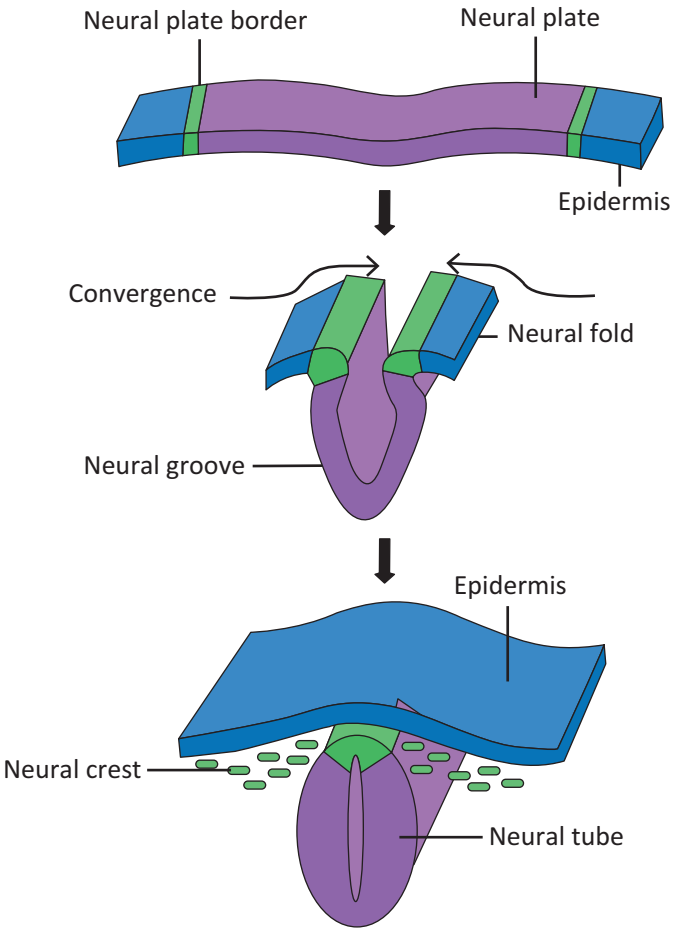

Fig. 2.2 An illustration of the neural plate during embryogenesis

Moreover, studies found that as many as 70 percent of cases could be prevented by increasing intake of folic acid prior to and during pregnancy (Wasserman & Holmbeck, 2016).

Children with spina bifida frequently have average to above average measures of intelligence with stronger language than visual perceptual skills. Difficulties are present in visual-motor integration, attention, and executive functioning (particularly comprehension, planning and organization, and decision-making (Hampton et al., 2013). A sizable minority of children with spina bifida also shows with learning disabilities (Ris et al., 2007).

Cell Migration Cell migration occurs throughout gestation and is regulated by physical as well as chemical processes (Carlson & Birkett, 2017). It begins at about 4 weeks when the neural tube closes. Stem cells proliferate inside the neural tube

and are the foundation for all of the structures of the brain. The migration process is rapid, and the cortical layers of the brain are visible by the fifth month of fetal development (Squire et al., 2008). This process is part of an intricate neuron-glial interaction. Glial cells are brain cells that are supportive cells in the CNS and are not involved in impulses. They generally provide support for neurons and are the most common type of cells in the CNS. The neurons are guided along the glial fibers by a chemical process to their proper location (Kolb & Whishaw, 2003). During this process the cortex thickens and sulci (ridges) and gyri (valleys) begin to appear. The longitudinal fissure (long fissure between the hemispheres) is evident at 10 weeks, the lateral sulcus (fissure between the frontal and temporal lobe) at 14 weeks, and a sulcus between the parietal and occipital lobes at 14 weeks. The central sulcus (between the frontal and parietal lobes) appears at 20 weeks of gestation.

During the prenatal and early postnatal periods, the neurons differentiate and got to genetically predetermine regions of the brain. When this system does not work as planned, neurons will go the wrong location or make inappropriate synaptic connections. Schizophrenia has been linked to cells incorrectly placed particularly in the frontal lobes (Buchsbaum et al., 2006). Learning disabilities have also been linked to misplaced cells or to cells that replicated too much (Galaburda & Kemper, 1979).

During this period of time, the cortical mantle is also being established. The cortex has six layers with the first developing neurons on the inside and later developing neurons passing over the first layer to migrate to layers 2 through 6. This process is called cortical lamination. Each layer has a distinctive group of cells that are defined by their inputs and outputs (Purves et al., 2001). It is estimated that approximately 2/3 of new neurons reach their goal in the brain while the others die or disappear. This process is important because more neurons are produced than are necessary with necessary cell death important for this process of neuronal proliferation and migration (Gazzaniga et al., 2013). It has been hypothesized that there is a limited amount of what is termed "trophic substance" which keeps the neurons alive. Thus, when this substance is depleted, the fetal neurons which are left will die (Brodal, 2016).

When migration is disrupted by environmental or toxic events, the child can suffer from serious neuropsychological deficits. Maternal stress, alcohol and other substance abuse, and poverty can cause significant disruption to the developing brain and result in lifelong disabilities (Johnson et al., 2016; Porter & Dyer, 2017). These disabilities can be cognitive, behavioral, and/or emotional in nature.

Formation of Synapses and Axon Development Neurons continue to develop throughout gestation. Axons (or the long portion of the neuron that connects with other neurons and conducts impulses away from the cell nucleus) follow what are termed "pioneer axons" which set the pattern of growth and direction. These pioneer axons have a high concentration of chemicals that propel the axons to the correct destination and are thought to have chemoaffinity between these axon ends and the neurons (Brodal, 2016). These axons grow rapidly while migrating and form pathways that connect the two hemispheres. As we discussed earlier, there are three commissures that connect the hemispheres. The anterior commissure appears

around 3 months of gestation, while the corpus callosum develops much more slowly and in fact some believe is not fully formed until early adolescence (Witelson, 1990).

Dendrites are those neuronal structures that conduct neural impulses toward the cell body of the neuron. They often have many branches that connect to other neurons for neuronal transmission. The more dendrites, the more intercommunication there is possible. Dendrites also have spines, which are protrusions that receive input from an axon. Again, the more spines are present, the more signals, which are possible between neurons. Dendrites and spines grow much more slowly than axons and are visible at around the seventh month of gestation. While axons grow prior to finding their home, dendrites do not develop until the cells are at the destination. Dendrites also continue to develop postnatally and can be affected by environmental stimulation.

While the development of synapses is poorly understood, they are generally seen around the fifth month of gestation (Carlson & Birkett, 2017). Synaptogenesis, or the development of synapses, occurs during gestation. Babies are born with over 100 billion neurons with each neuron having many branches. This makes a possible quadrillion connections through synapses. Initially only 17 percent of neurons are linked in a baby's brain (Carlson & Birkett, 2017). These connections increase dramatically in the first few years of life, and by the age of 2, the frontal lobes have 50 percent more synapses than are present in adults (Gazzaniga et al., 2013). Synapses are eliminated as the child grows and the brain becomes more efficient in function and shows more refinement of ability. In this case less is more as the synapses that remain provide more precise neuronal connections. Unused synapses basically die away if they don't wire up to axons. This process of pruning is termed apoptosis and basically reduces gray matter in the brain throughout childhood as the brain becomes more efficient (Giedd et al., 1994; Gogtay et al., 2004). It is also during this period that the migration of cells and apoptosis can be disrupted by environmental, genetic, and viral infections. These synaptic networks become elaborate in the postnatal period as dendritic arborization (increase in dendritic spines that look basically like limbs of a tree) increases. During the third trimester of gestation, the brain enters a growth spurt that continues until 2 years of age.

Myelination At the same time, as apoptosis and synaptogenesis are occurring, the axons are becoming coated with a fatty substance called myelin that makes up the white matter. This process proceeds from deep in the brain to the outside and from posterior to anterior. Initially most neurons are not myelinated and have dendritic spines. Myelination continues throughout childhood and into adolescence and the early twenties (Gogtay et al., 2004). It occurs in the primary sensory and motor cortices first (prior to birth), and then the secondary areas of the basic senses (auditory discrimination, motor planning, visual discrimination, sensory discrimination) complete myelination by the age of 4 months postnatally. The association areas of the frontal and parietal lobes do not complete myelination until much later and for some individuals not until the twenties (Fredrik et al., 2007). Subcortical structures such as the amygdala (emotional processing) and the hippocampus (memory)

increase in volume until around the age of 30 and then begin to gradually decline (Nyraradi et al., 2013). These changes also occur in the caudate and in cortical thickness (Fair et al., 2013).

There are sensitive periods during this development when the brain changes drastically. During these periods the brain is fairly "plastic" and responds to environmental changes and experiences in a more exaggerated manner. The length of these periods varies depending on the child. The experiences the child is engaged in can change the function and complexity of these circuits for better or for worse (Holtmaat & Svoboda, 2009).

Gender Effects The study of gender effects in the fetus is in its infancy. A literature search of these key terms found no articles. The studies that do exist are for infants and toddlers as well as adults. Males have been found to be at higher risk for learning disabilities, ADHD, and autism (Schore, 2017). Male brains develop more slowly than female brains putting them at higher risk for difficulties in childhood and adulthood (Schneider et al., 2011). It has been suggested that one of the reasons that males are more often diagnosed with schizophrenia is that the brain deficits begin in the fetal period when the brain becomes sexually differentiated through hormones (Holden, 2005). In addition it has been accepted in neuroscience research that males are prone to psychiatric difficulties that appear earlier in development while female difficulties most frequently appear later in life (Llorente et al., 2009). Schore (2017) suggests that gender differences in brain development are related to differences in sex hormones, social experiences, and the rate of brain maturation particularly in the right hemisphere. He goes on to suggest that the *"stress-regulating circuits of the male brain mature more slowly than those of the female in the prenatal, perinatal, and postnatal critical periods, and that this is reflected in normal gender differences in right-brain attachment functions"* (p. 19). He goes on to hypothesize that due to this slower maturation process, males are more vulnerable to stress, brain injury, and environmental effects than females particularly since the right hemisphere is important for social and emotional development.

Using animal studies there is emerging evidence that the male fetus may also be at higher risk for neurodevelopmental problems when exposed to substances during pregnancy. It has been found that male rats showed a decrease in the dopaminergic system that resulted in increased dysregulation while females, showing the same decrease, showed less dysregulation (Dow-Edwards & Torres-Reveron, 2012). Additional studies have found that males exposed to cocaine in utero show problems with attention, emotional control, impulsivity, and general dysregulation while females do not show these same difficulties (Kestler et al., 2012). These authors suggest that because male brains develop more slowly, their brains are at higher risk for damage from cocaine than are females.

Culture Effects Cognitive development occurring after birth occurs within a culture or ethnic group (Gauvain & Perez, 2015). Neurodevelopment prior to birth is less likely to be affected by culture with the exception of nutrition and prenatal practices. The influence of culture can transform the brain as the child is exposed to environmental stimuli. Culture-based learning affects not only skills and abilities

but also how emotion is expressed and perceived (Kennepol, 1999). It has been hypothesized that cultural influences on brain organization (after birth) relate to the making of appropriate neuronal connections based on experience in the culture, activating specific neural networks that are developed through cultural experiences, and learning how to adapt appropriate to the culture to novel environments (Luria, 1980). Luria goes on further to state that the "social contact and objective activity by the child" are related to the development of the association areas that develop with experience (p. 31).

Changes in brain structure have been found based on cultural experience in studies of stroke patients from China (Yu-Huan, Ying-Guan, & Gui-Quing, 1990). Aphasia was more common in these patients following a right-sided lesion for patients from a majority ethnic group, the Han (crossed aphasia). The Han language is basically nonphonetic and picture based. Crossed aphasia was rarely seen in the Western European population. Wernicke's aphasia is rarely seen in the Han population. Yu-Huan et al. (1990) suggest that for this population language is lateralized in the right or both hemispheres rather than most predominately in the left hemisphere. What is not known is whether this difference is passed on genetically and there is altered brain development in utero.

Additional findings are present in Japan particularly in languages which are logographic. In this case Japanese use a phonetic language for reading and a logographic language for everyday written Japanese. In aphasics with left-sided lesions, they can read fluently using the phonetic language but not the logographic language possibly implicating a right-hemisphere language system (Elman et al., 1981).

These areas begin to highlight some possible adjustments that are made from cultural contexts. Further studies have also found commonalities among cultures in neurodevelopment and organization (Gauvain & Perez, 2015). For the most part, human brain structure has not changed in the past 50,000 to 10,000 years (Harris, 1983). Reading and writing skills are recent developments in our evolution, and thus these areas may be more susceptible to culture and environmental changes. It has been hypothesized by Kennepol (1999) that the basic neural structures are preprogrammed to develop in a flexible manner following interaction with the environment (Semrud-Clikeman & Bledsoe, 2014). One of the difficulties in this area is the dearth of empirical studies to verify these conclusions which are based on behavioral data. There is ethnographic and social experimental evidence that culture may be transmitted genetically as well as through experience (Perez-Arce, 1999).

Many children whose parents have immigrated to another country are now bilingual. One study evaluated the brain differences in Spanish-English bilinguals (Felton et al., 2017). Findings were that thicker right than left cortices were present for bilinguals with monolinguals showing the reverse pattern. For bilinguals the mid-anterior and central portions of the corpus callosum had a greater volume compared to the one-language speakers. Thus, changes in structures were likely present with experience. It is not clear whether these differences are later genetically inherited or whether they are based solely on environmental input at early ages. Further study in this area is certainly needed particularly in the USA as ethnic minorities continue to grow and prosper and our understanding of the neurological basis of language is crucial.

Development of Higher-Order Cognitive Abilities

Challenges to Brain Development

Brain development can be affected by malnutrition, disease, injury, and inadequate stimulation as well as experiencing neglect and abuse during this very sensitive developmental period (Porter & Dyer, 2017). Disruption can result in problems with infant regulation both physical and emotional (Kouros et al., 2014). Enrichment activities (toys, social stimulation, novel experiences) have been found to improve changes in brain structure, function, and gene expression (Hirase & Shinohara, 2014). It has been hypothesized that poverty can shape the brain at many levels including at the molecular, neural, and cognitive levels (Lipina et al., 2011). Thus, brain development is transactional in nature where the genetic and environmental influences interact to produce the individual (Shonkoff & Garner, 2012). Socioeconomic status (SES) has been found to have a larger influence on brain development than genetics for individuals at the low end but not for those in high-SES environments (Chiang et al., 2011; Turkheimer et al., 2003). This vulnerability can be moderated by genetic influences explaining why children from the same family show different responses to the same environment with some more resilient than others (Ellis et al., 2011).

To complicate matters further, epigenetic research has found that the environment itself plays a role in how the genetic code is expressed (Johnson et al., 2016). Maternal care can affect the development of the brain in that there is more efficient regulation for negative feedback from the hypothalamic-pituitary-adrenal (HPA) axis that allows for a better regulated stress response and cognitive performance (Essex et al., 2013). Better maternal care resulted in better emotional regulation and cognition. Of even greater concern is the emerging finding that this modification can be transmitted across generations as well as in gene expression in the brain (Essex et al., 2013; Sheridan & McLaughlin, 2014).

Stress can also negatively impact the fetal and infant brain. Children growing up in low-SES environments are more likely to be exposed to family conflict, many people in the same household and many changes in who lives in the home, neighborhood disruption, and anger all making for the experience of "toxic stress" (Evans et al., 2011; Lupien et al., 2009). This stress is thought to program the HPA axis leading to excessive secretion of glucocorticoids (Lupien et al., 2009). This chronic stress on a child's brain development can lead to hyper or hypo activity of the HPA axis leading to changes in the prefrontal cortex (important for insight and impulse control), the amygdala, and the hippocampus (Lupien et al., 2009). This excessive glucocorticoid exposure can affect plasticity and hence neurogenesis in the hippocampus and synapsis. This is particularly devastating to the child's development as it affects the child's ability to cope, to develop coping mechanisms, and to undermine cognitive development (McEwen & Gianaros, 2010).

Children raised in poverty are more likely to be disciplined more harshly and inconsistently as well as experiencing less nurturing and positive reinforcement

(Conger et al., 2010). Studies of children in institutions or who have documented maltreatment have found smaller gray and white matter volume in childhood and less hippocampal volume in adulthood (Belsky & deHaan, 2011).

Susceptible Cognitive Areas of Development The areas that are most susceptible to changes based on poverty and stress include basic skills of language, literacy, and executive functioning. Language is based in the left temporal lobe and has been found to be strongly associated with childhood SES (Noble et al., 2007). Research has found that higher-SES children have more neural specialization for reading, and when a reading disability is present in these children, compensatory systems are more readily available for remediation (Raizada et al., 2008). For lower-SES children, lack of experience and exposure to literacy seems to result in neural differences particularly in the language centers of the brain (D'Angiulli et al., 2012).

Learning and memory can also be associated with SES. The hippocampus is the main structure that supports learning and memory and has many glucocorticoid receptors. If you recall, glucocorticoids are part of the HPA axis and respond to stress. Too much glucocorticoids can interfere with hippocampal development. Neuroimaging has found that higher-SES children have larger hippocampi with low-SES children showing smaller hippocampi even when they reach their fifth decade of life (Jednorog et al., 2012; Staff et al., 2012). An intriguing recent finding has been that family income and learning may be mediated by hippocampal differences and are inversely related (Hair et al., 2015). In addition, educational experiences being related to hippocampal volume decrease with individuals with less education showing greater hippocampal volume loss than those with higher educational attainment (Noble et al., 2012). Thus, nurturance, educational experience, and enrichment have effects on the hippocampus, which is a crucial structure for new learning to take place.

The amygdala is responsible for emotional processing. Functional neuroimaging studies have found that children from lower-SES backgrounds as well as those from nonoptimal environments have less regulated functioning in the amygdala (Kim et al., 2013). In addition, problems with attachment, maternal depression, and difficulty with bonding have been found to be related to a larger amygdala in childhood and adolescence. A larger amygdala is associated with more emotional dysregulation and poorer emotional control (Gilliam et al., 2015).

In addition to the hippocampus and amygdala, the prefrontal cortex is an important structure for executive function, insight into behavior, impulse control, and higher-order planning and reasoning. Aspects that have been found to be related to smaller prefrontal cortex development include deprivation, stress, negative parenting, and less use of language to explain concepts and ideas (Hair et al., 2015). One interesting study using a longitudinal design found a relationship between low SES in childhood and later problems with aggression and conduct to smaller prefrontal volume (Holz et al., 2015). Studies have also found that when high levels of cortisol are present (the HPA axis), children are in deprived and higher stress environments (Blair et al., 2011). Thus the prefrontal cortex is exquisitively sensitive to stress, the HPA axis, and deprivation as well as poor parenting.

Summary Thus, poverty and family stress can alter the brain's trajectory and place the child at high risk for emotional and behavioral problems. Particular structures that are vulnerable are in the limbic system, the language system, and the prefrontal cortex. These structures basically allow the child to adapt to his/her environment and the changing requirements of that environment. When these structures are compromised, the resulting adaptation of the child and eventually the adult is less than optimal. From the research the key factor is poverty and stress rather than ethnicity or culture that shapes the child's brain and resulting mental health. What is most alarming is that this brain change appears to alter the genetics of the child and can be passed down to ensuing generations almost guaranteeing continuing poverty and poor functioning. Interventions to improve living conditions and stress are indicated for these children in order to circumvent the inevitability of these difficulties for future generations. It is not clear whether these difficulties can be reversed, but public policy and interventions by schools and psychologists would seem to be a first step toward making life more palatable for these children and their families. Clinical, counseling, and school psychologists need to be aware of these effects on a child's development and brain in assisting parents to understand the resulting trauma that can result from excessive stress and environmental challenge.

The Importance of Understanding Neurodevelopment for the Clinician

While it is not expected that general clinicians in psychology (school, counseling, and clinical) have extensive training in neurodevelopment, it is not uncommon for these professionals to see children who have various disorders for therapy and/or assessment. Moreover, chronic diseases such as diabetes and genetic disorders often are accompanied by neuropsychological deficits that can translate into difficulties with adaptation and emotional functioning. More and more children with significant medical diseases are now surviving and frequently experience emotional difficulty from the stress of their disease and treatment as well as family stress. Children who recover from cancer, leukemia, organ transplants, and brain injuries frequently experience difficulty with memory and attention as well as impulse control. These issues often translate into problem socially as well as emotionally and frequently require psychotherapy.

Genetic disorders also pose risks to neurodevelopment for children. There is evidence for a predisposition for depression and anxiety for children with families with a history of these disorders. This is true also for schizophrenia and bipolar disorder. Further children with genetic disorders such as Hurler's disease, adrenoleukodystrophy, Williams syndrome, and others are surviving, and treatments have been developed. While these treatments are lifesaving, they also take a toll on the brain and can result in difficulty with attention, memory, vision, hearing, and mobility. These aspects often can affect the child's adaptation, and psychotherapy is frequently recommended for the child and his/her family.

Biological and Environmental Factors

Several other factors can also impact the child's functioning and result in referral to specialists. The effect of stress on the fetus was discussed earlier. Nutritional deficiencies, particularly in the last trimester of the pregnancy, can affect brain size and weight resulting in fewer brain cells. Maternal hypotension can be as dangerous for the fetus as hypertension. Both of these disorders can cause difficulty with migration of cells and proliferation of synapses and circulation problems in the fetal brain resulting in stroke-like areas to be present.

The use of alcohol during pregnancy has been widely publicized as having serious consequences for the fetal brain. It has been estimated that over 40,000 children are born with fetal alcohol effects of some degree each year (Streisguth et al., 2004; Luu et al., 2017). Fetal alcohol syndrome effects can vary from mild to very severe depending on how much the mother drank and when (Boys et al., 2016). The psychologist will see these children in psychotherapy, and it is important to recognize that impulse control and emotional control are part and parcel of these disorders and usual behavioral interventions are often insufficient for treatment. It is also important for the clinician to be aware that alcohol often results in frontal lobe symptoms where learning from mistakes and insights into behavior are negatively impacted.

Birth complications can also result in difficulties in the child. Prematurity can affect the child in many ways. While many premature infants may progress well, there are some that experience significant problems with attention and executive functioning around the age of 9 or 10. Birth complications have been strongly implicated in schizophrenia and psychosis including low and high birth weight, breech presentation, vacuum extraction, placenta infarcts, and others (Liu et al., 2019). The clinician is well advised to obtain a comprehensive pregnancy and delivery history to fully appreciate these risk factors.

This is a very brief description of these disorders from a neurodevelopmental perspective. Chapter 4 will discuss these areas in much more detail. It is important to recognize that the frontal lobe is most susceptible to problems in neurodevelopment. These difficulties may not show up until 9 or 10 when independence and emotional control are expected. The clinician working with these children will profit from understanding the development of these structures and how it impacts later development particularly in the emotional and social domains.

Conclusions

Neurodevelopment is becoming a more and more important aspect for clinicians as children with various disorders are now surviving and thriving following treatment. It is also important in helping parents to understand why their child is not learning at the expected pace or why their child is experiencing significant problems with emotional control, impulsivity, attention, and hyperactivity. Depression and anxiety

have been linked for some children to neurodevelopmental and genetic causes. Fetal alcohol syndrome, genetic disorders, prematurity, environmental toxins, and other impacts on the fetus and baby have also been found to impact neurodevelopment with these children frequently requiring psychotherapy and/or assessment to progress as far as they can.

As described above there are critical periods in fetal neurodevelopment with the first 2 weeks crucial for the formation of the neural tube and then later the synaptogenesis and selective cell death that occurs to form synapses and to trim back neurons that have not found their place. Birth complications can cause significant problems for the child's neurodevelopment as can stress and domestic violence. Stress, poverty, violence, and substance abuse appear to be far more predictive of later neurodevelopmental difficulty than the effects of culture or ethnicity. Research has indicated that the ethnicity of the child is not as important as poverty, stress, and domestic violence in predicting later neurodevelopmental disorders. These findings are critically important as some mistakenly lay learning and adjustment difficulties on children of poverty as a result of ethnicity and culture rather than to environmental factors that can be corrected. Support of children, and their families, who are in adverse situations can improve their future. It is sobering to recall that continued stress over long periods of time can result in genetic transformation of the telomeres of the chromosomes that is then transmitted to the next generation. It would appear that one of the more ready solutions for these difficulties is political and requires the will to change how we work with children and families who are in poverty and who live in dangerous situations. I can recall one of my clients saying to me (he was 9): *"how do you expect me to practice my reading at night when I can hear shots and fighting outside my window?"* From the mouths of babes!

Discussion Questions

1. Describe the lobes of the brain, their function, and their development.
2. Describe the process during the first 2 weeks of gestation. Describe the difficulties that can arise from defects in development during this time.
3. What are apoptosis and synaptogenesis? Describe these processes and how important they are for neurodevelopment.
4. Describe the gender differences in brain development. Are there any? If not why not?
5. What effects does poverty and violence have on the developing brain? Why do you think these aspects affect the developing fetus to that extent? How would you work with these children and their families?
6. The frontal lobe takes the longest to develop. How do you think this increased length of development is necessary for this structure? How do these findings map onto the work of Erickson, Freud, and Piaget?
7. How would you work with a child who has survived treatment for a life-threatening disease? What types of educational information would be most helpful for him/her and his/her family?

8. What role do you believe culture has in supporting the neurodevelopment of the child? What gender differences may also affect neurodevelopment?
9. The limbic system is an important aspect of neurodevelopment. How would you work with a child who is very dysregulated and who has difficulty learning from his/her mistakes? What areas of the brain would be most affected to result in these difficulties?
10. Why is this information important for the clinician to master even when not in neuropsychological practice?

EPPP Sample Questions

1. What is the main function of the meninges?

   (a) To provide cushioning for the brain
   (b) To provide air between the brain and skull
   (c) To take away waste and unneeded substances
   (d) To facilitate consciousness and attention

2. The brain stem involves several functions including:

   (a) Thinking, eating, and sleeping
   (b) Body movement, thinking, and eating
   (c) Respiration, swallowing, blood pressure
   (d) Breathing, thinking, moving

3. Injury to the cerebellum can mostly result in:

   (a) Movement disturbances
   (b) Emotional disturbance
   (c) Out-of-body feelings
   (d) Learning problems

4. The neural tube is the foundation for:

   (a) The brain and spinal cord
   (b) The brain stem and hippocampus
   (c) The basal ganglia and hippocampus
   (d) The brain stem and basal ganglia

5. The basal ganglia are made up of:

   (a) Globus pallidus, neural tube, putamen
   (b) Caudate, brain stem, hippocampus
   (c) Putamen, globus pallidus, brain stem
   (d) Caudate, putamen, globus pallidus

   Answers: A, C, A, A, D

Proactive Readings

Transcending the past

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Transforming the Future

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