Neurocounseling: Bridging Brain and Behavior

Neural development and change during childhood and adolescence

By Thomas A. Field & Michelle R. Ghoston

In this three-part series on neurological factors that affect child and adolescent development (and aligned counseling interventions to address them), we will explore neural development and change during the child and adolescent period, hypercortisolism and the metaplasticity hypothesis, and the delivery of neuroeducation to children and adolescents. More information about these concepts is provided in our book, *Neuroscience-Informed Counseling With Children and Adolescents*, which was recently published by the American Counseling Association.

In this month's article, we cover major topic areas of neural development and change during the child and adolescent period. Understanding these areas will help inform counseling approaches for working with children and adolescents.

Synapse formation and myelination

Neural development during the early childhood phase helps us understand why infants and children gain abilities and skills over time. As they age, infants become able to complete progressively complex sensorimotor tasks such as sitting up, crawling, walking and running. They can reach and grab objects. They can manipulate their facial muscles to make a range of sounds and words. They become able to differentiate smells and can see objects at longer distances. Higher-order cognitive functions also develop, including grasping object permanence (e.g., remembering that an object will be in the same place where it was left, requesting an object they played with the day before), learning sequences such as bedtime routines, and understanding receptive language.

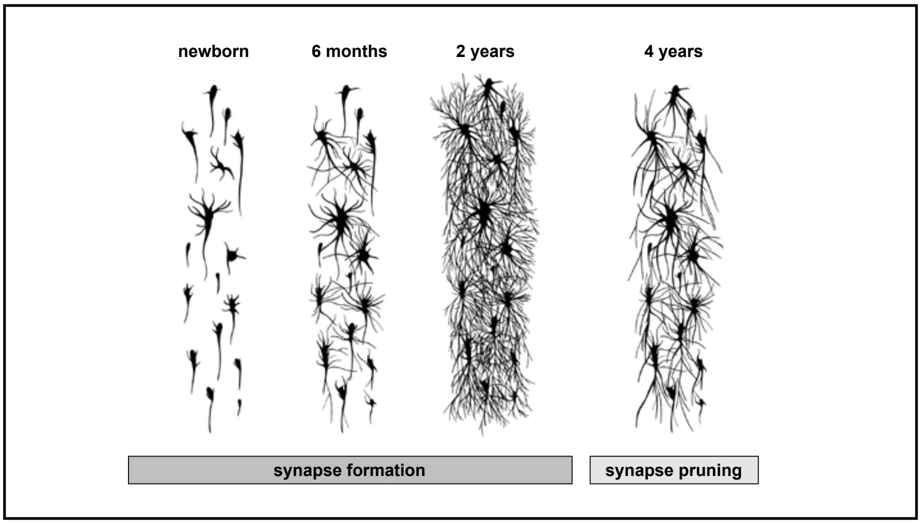
Neural growth is most rapid in utero during the fetal stage. Most neurons in the brain have been developed by seven months gestation. However, neurons in the fetal brain have limited connections with other neurons, which has important implications for basic neurophysiological functioning. After birth, the connection between these cells becomes most notably pronounced. The development of new synaptic connections between cells is termed *synaptogenesis*. The neurotransmitter glutamate plays an important role in the development of these new synapses.

In addition, myelination occurs rapidly in the postnatal period. Readers of this column may be aware that cells operate through electrical signaling and conduction. During neurotransmission, ions with a positive or negative charge enter a cell and create an action potential when the threshold is reached for a polarized electrical charge. This results in an electrical charge being sent down the cell to the axon terminal buttons, which signal with another neuron and release neurotransmitters from vesicles into the synaptic cleft. Myelination speeds up the process by which this charge passes through the cell.

Myelination is the process through which the neuron's axon is covered by a fatty sheath called myelin. The myelin assists the cell with electrical conduction. A myelinated axon can carry an electrical signal from the dendrites to axon terminal buttons with 5,000 times less energy. In short, because of both synaptogenesis and myelination, connections between neurons become more numerous, and messages are passed more rapidly between neurons.

Areas of the brain myelinate at different rates. Neurons in sensorimotor structures tend to myelinate earlier than do neurons in prefrontal structures. Myelination of neurons in the sensorimotor cortex is typically complete by the end of the second year. In contrast, neurons in the prefrontal structures continue to myelinate until a person is in their mid-20s. These different trajectories of myelination help us understand why children and adolescents often have sensory and motor development that outpace executive functioning associated with the prefrontal cortex, such as planned behavior, emotion regulation and frustration tolerance, and the choosing of long-term benefits over short-term rewards.

As a current parent of two young children, Thom has a personal example of these different myelination trajectories. When Thom is cooking dinner in the late afternoon, his children begin imploring him for snack foods. Their sensory systems are activated by the smells of food cooking on the stove, and these smells generate a sense of hunger. Because their prefrontal structures are still under development, their ability to regulate their hunger impulse through top-down prefrontal control (e.g., "I can wait to seek food because we will be eating dinner soon") is not the same as it is in adults. Parental attempts to help children delay gratification is often futile and less productive than providing some aspects of the meal early (e.g., fruit) to quell their hunger pangs until dinner. Reprimanding children for demanding snack foods is not effective. When the children's sensory systems are activated the next evening while dinner is cooking, they may again struggle to regulate their hunger impulses regardless of earlier parental discipline.



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Why is it that structures in the sensorimotor cortex develop before structures in the prefrontal cortex? It's because the developmental tasks and needs of infants require sensorimotor abilities (e.g., movement) before executive functioning abilities. For example, a newborn needs to request nourishment. Thus, the ability to cry, root and make gestures with their hands to imply hunger are essential early skills. In contrast, being able to self-reflect on experiences is less pressing at the newborn stage. Imagine that a child's neural development progressed in the opposite trajectory. If a child was able to hold in-depth conversations about existential issues at the neonatal stage and yet could not request food, their survival would be threatened.

Synaptic pruning

At age 2, children have the most synaptic connections they will ever have in their lifetimes. This high connectivity between neurons supports rapid learning. For example, synapses can be formed within minutes or hours after an activity in response to the activity and environmental events.

In fact, at age 2, children have more connections than they functionally need. Unused synaptic connections are therefore eliminated through a process called *pruning*. There are two major periods of synaptic pruning during childhood and adolescence: at ages 2-5 and again during late adolescence. Pruning occurs when microglia (supportive cells in the central nervous system) engulf synaptic structures through a process called phagocytosis. This process continues throughout the early childhood period.

By age 10, 50% of a child's synapses have been eliminated. This has implications for language development. Children are most easily able to learn new languages at younger ages when their synaptic connections are most abundant. A graphic depicting synapse formation and pruning is presented at the top of this page.

Myelination and reduced synaptic density result in cortical thinning, which is thought to assist with cognitive efficiency. Synaptic pruning is thus essential to healthy central nervous system functioning. Guomei Tang and colleagues in 2014 reported that an overpreponderance of synapses can result in overcommunication between brain structures, creating confusion and "noise" within the brain. During synaptic pruning, a child may be more emotionally sensitive and irritable. Some have postulated that synaptic pruning places a child at risk of developing mental disorders such as autism in early childhood and depression, bipolar disorder and schizophrenia in adolescence.

It is worth noting here that some conditions, such as autism, have been associated with problems in synaptic pruning. Tang and colleagues reported that children with autism tend to experience reductions in synaptic pruning. As a result, children with autism have an increased density of receptors on dendritic spines. The protein mTOR appears to be overproduced, which reduces synaptic pruning. In mice studies, rapamycin appears to reduce mTOR, which in turn leads to an increase in synaptic pruning. Some experts are thus proposing that rapamycin could be a potential early treatment for autism. In addition, autism has been associated with greater numbers of degraded and old neurons, which is suggestive of problems with glial (and especially microglial) function.

Imbalance theory

During adolescence, neural growth and myelination continue to occur in structures of the brain. Adolescent neurogenesis occurs at four to five times the rate of adult neurogenesis. Subcortical structures, such as ones located in the limbic region (e.g., amygdala, hippocampus, hypothalamus, thalamus) and striatum (e.g., basal ganglia), outpace growth in the prefrontal region. The nucleus accumbens is located in the striatum and is a major site of dopamine production.

During adolescence, dopamine production increases two- to sevenfold. Thus, adolescents experience greater development of brain structures associated with emotional experiencing and motivation/reward-seeking compared with structures associated with processing and controlling these emotional experiences and reward-seeking impulses. A research team led by Mariam Arain in 2013 proposed that these different trajectories of brain development may explain why adolescents (as compared with adults) weigh the benefits of risk-taking actions more strongly than they do the drawbacks of a potential action.

Research teams led by B.J. Casey have proposed an *imbalance theory* of brain development during adolescence to explain this phenomenon. The imbalance theory proposes that these different trajectories of neural growth in adolescence help us understand why teens 1) experience greater depths of emotion without the prefrontal architecture to process and regulate these emotions and 2) are more attracted to novelty and high-sensation (i.e., thrill) experiences even if those experiences are potentially threatening.

Adriana Galván proposed that the development of the dopaminergic system during adolescence helps us understand why substance use markedly increases during this period. According to a 2013 paper by Arain and colleagues, most addictions begin during the adolescent period. As adolescents age and become adults, they develop the structures and circuitry (e.g., frontolimbic circuitry) to process and regulate emotions and impulses.

An adolescent's deeper emotional experiences are paired with increased social awareness and recognition as the frontal region of the brain continues to develop. A research team led by Wouter van den Bos and colleagues wrote in 2011 that neural proliferation and myelination of the dorsolateral and medial regions of the prefrontal cortex occur during the adolescent period. Correspondingly, adolescents develop emotional insight and awareness of both their own thoughts and those of others around them.

These abilities are often termed *mentalization* or *theory of mind*. These terms describe a person's self-reflective ability to "think about thinking," known as *metacognition*. Adolescents who develop this self-awareness are able to understand their own thoughts and become aware of the thoughts of others. Mentalization ability thus enhances relational depth, especially with peers. For example, an adolescent may become aware that a peer is upset about being socially excluded by their peer group and intentionally reach out.

This self-awareness can also manifest in overly high levels of self-consciousness. For example, teens often experience heightened sensitivity and fears of social rejection and ostracism, called *rejection sensitivity*. These fears are associated with activation of the amygdala, anterior cingulate cortex, insula and striatum. A research team led by Carrie Masten found in 2011 that heightened rejection sensitivity is associated with increased risk for depression.

Alongside hyperemotionality, the second major period of synaptic pruning occurs during adolescence. As is the case with younger children, adolescents are at greater risk of emotional vulnerability during this period. The onset of many mental disorders begins during adolescence.

Counseling implications

Early childhood: When counseling children and adolescents and working with parents, it is important for counselors to be aware that the frontal lobe has a slower growth trajectory during childhood compared with other regions and structures of the brain. Prefrontal structures are still under development until a person reaches their mid-20s. As a result, young children should not be expected to have fully developed executive functioning skills and self-awareness. Children may struggle to regulate their emotions and impulses. Caregivers and counselors should consider this when responding to a child.

"Thinking before acting" is a tall order for all of us, but it is particularly difficult (if not impossible) for children whose prefrontal structures are still under development. Thus, effective parenting approaches during the early childhood period typically involve positive reinforcement and instruction rather than punishment when children are struggling to control their emotional responses. For example, a child who hits a sibling or playmate for taking one of their toys needs guidance regarding how their actions affect others (in this case, another child). Punishing the child's actions by taking away preferred objects and activities (negative punishment) may only generate resentment toward the adult who delivered the disciplinary action rather than help the child learn to become sensitive to the responses of others (which takes some time to learn). The child may not necessarily understand why their action was hurtful to others unless it is explained to them.

Children may also have primitive empathy responses because mentalization and self-awareness/other awareness do not fully occur until adolescence. Children thus often perceive the world through their own experience and may have trouble predicting how their actions might affect others. Imagine that a child is tasked with buying a gift for a friend. Children are likely to choose an item that they personally like because it can be difficult for them to predict what another person likes. Adults have a role in helping children understand the consequences of their actions without punishing them for failing to display abilities that they have not fully developed.

Adolescence: During adolescence, teens develop mentalization and theory of mind capacities. Enhanced self-awareness results in adolescents having some requisite ability to benefit from insight-oriented counseling approaches such as cognitive behavior therapy. During adolescence, many teens seek independence and benefit from counseling (and parenting) approaches that grant them autonomy while also providing guidance regarding their choices and options in a situation. Considering long-term (not just short-term) objectives when making decisions can be particularly helpful.

For example, imagine an adolescent who is angry at a dating partner for cheating on them and has impulses to smear that partner's name at school by spreading negative rumors. The adolescent needs validation of their feelings and to process what their ultimate goal is in the situation. If the adolescent actually wants an apology and reconciliation more than they want to exact revenge, or if they want to maintain a positive reputation among their peers, then spreading rumors might further distance them from their ultimate long-term objective.

Parents can often struggle with transitioning from active and directive roles in child-rearing, such as problem-solving for the child. As children grow older and transition into adolescence, they may need their parents to take on more supportive and facilitative roles, such as providing active listening and withholding advice in most situations unless requested. Counselors using enactments and experiential role-plays can help caregivers take a different approach in responding to their adolescents.

During an enactment, the caregiver and adolescent dialogue about a recent event that upset the teen at home or at school. During the ensuing dialogue, the counselor can coach the caregiver to demonstrate active listening and to refrain from providing advice or problem-solving unless requested by the adolescent. This can often be a difficult task for caregivers, who may have become quite adept at directive problem-solving through earlier parental experiences. With feedback, caregivers eventually become more comfortable and skillful at providing listening and support and refraining from advice or problem-solving unless requested.

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To learn more about how neuroscience can inform child and adolescent counseling, check out our new text published by ACA, *Neuroscience-Informed Counseling With Children and Adolescents.* ❖

Thomas A. Field is an assistant professor of psychiatry at the Boston University School of Medicine. He is a licensed mental health counselor, licensed professional counselor, national certified counselor, certified clinical mental health counselor and approved clinical supervisor. Contact him at *tfield@bu.edu*.

Michelle R. Ghoston is an assistant professor at Wake Forest University. She is a licensed clinical mental health counselor, licensed professional counselor and approved clinical supervisor. Contact her at *ghostonm@wfu.edu*.