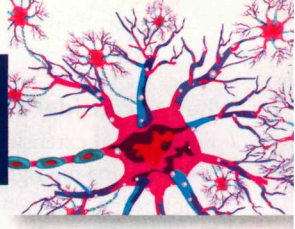

The evolving adolescent brain

Adolescence holds a certain mystique and frequently presents considerable challenges for adults, including caregivers and even counselors. The tween and teen years represent a time of upheaval and transition, often marked by struggles with perceived rebellion, risk-taking, individuation, less than optimal decision-making, changing social roles, emotional lability and pervasive feelings of being misunderstood. Although regularly grouped with children in counseling texts, adolescence represents a unique population better understood through a neurophysiology lens.

In his book *South of Broad*, novelist Pat Conroy professes, "It is an unforgivable crime for teenagers not to be able to absolve themselves for being ridiculous creatures at the most hazardous time of their lives." Although beyond the scope of a single column, I will attempt to shed light on key aspects of adolescent brain development to enhance your work with these clients and their families, thus perhaps absolving to some degree this population for being at times so "ridiculous."

Extending from roughly age 11 into one's early 20s, adolescence is a second critical period in brain development that can represent the onset of mental health concerns such as anxiety and depression. The physical, psychological and social changes characteristic of this span are indicative of the dramatic shifts going on in the brain. These neurological changes, on different developmental trajectories, create a perfect storm of modifications, epitomizing Conroy's description of this time as "hazardous." Although the brain has reached nearly its full size by the time a child turns 6, the density and organization of various brain regions and the connections between them shift as the brain adapts to internal and external forces. This process is known as neuroplasticity.

Advanced structural and functional imaging technologies reveal that adolescents experience considerable changes in the volume of their grey matter or neuron cell bodies (think of these as the actual computers in a computer network), in their white matter or connections between cell bodies (the network cables between computers) and in their limbic system (the emotional powerhouse of the brain), which is also involved in risk and reward. Such changes closely correspond with the surge of hormones that accompanies the onset of puberty.

Grey matter

The volume of cerebral grey matter fluctuates during adolescence, most notably in the frontal and parietal cortices and cerebellum. Within these areas, the volume of neurons peaks during early adolescence and then begins to decrease into late adolescence, following a bell-shaped developmental curve, as suggested by B.J. Casey in a 2008 article in the *Annals of the New York Academy of Sciences*. This decrease represents a pruning of connections between neurons that are not readily used.

One of the final areas to prune is the prefrontal cortex (pFC), which is the very front part of the brain. This area is responsible for executive control, rational thought, decision-making and emotional regulation. Boys and girls show differences in grey matter volume trajectories in the pFC, with matter peaking at 13 for boys and 11 for girls and then decreasing in both sexes during late adolescence.

It may seem counterintuitive that decreases in grey matter are associated with development. This reduction represents a refinement in mental processing and the area becoming more functionally adept. For instance, as grey matter in the pFC decreases, cognitive abilities and logical reasoning skills begin to improve. Looking at sex differences in conjunction with this process, researchers have found that on average, girls begin to enhance such skills earlier than boys.

White matter

Unlike the volume of grey matter, white matter follows a linear developmental pattern, continuing to increase throughout middle and late adolescence. White matter gets its color from the fatty myelin sheath that covers the axon, or network cable, a process called myelination. This fatty layer allows for greater conduction of electrical signals and a faster rate of processing.

In essence, different areas of our brain can communicate faster and more clearly, which means that, neurologically, adolescents become more efficient processing and responding to constant streams of information. This better communication also means, for instance, that the pFC can better regulate other areas of the brain, including structures within the limbic system. Overall, boys have more white matter, yet the development of white matter matures faster in girls.

Limbic system

Along with changes in cortical areas, concurrent changes occur in limbic regions. The limbic structures that demonstrate considerable change during adolescence include:

- The amygdala (the emotional core of our brains, particularly around fear and anger)
- The hippocampus (responsible for memory consolidation)
- The anterior cingulate cortex (the cortical area surrounding the limbic region that is involved in cognitive and emotional functions such as empathy, emotion regulation, attention and goal-directed behavior)
- The nucleus accumbens (related to motivation, pleasure and addiction)

Synaptic pruning and refinement occur in each of these areas, with age and sex differences also being present. For example, the volume of the amygdala is larger in boys, whereas the hippocampus is larger in girls. This may explain why boys tend to be more aggressive, while girls have a stronger capacity for memory, especially around social cues.

In general, limbic regions mature before the pFC. It is thought that many of the behavioral and emotional challenges that adolescents face are due to a deficiency in executive functioning or an underdeveloped pFC. However, the pFC has not fully developed at the onset of adolescence. In addition, the emotional system of our brain is in overdrive, and the connections between the pFC and the limbic regions are not fully formed until our late teens and 20s. This differential development drives the changes in risk-taking, social cognition, empathy and self-consciousness that adolescents face. Take self-consciousness, for example. As adolescents are just starting to develop the capacity for cognitive aspects of empathy and really grasp the perspective of others, their emotional response to that may be exaggerated. Additionally, they may not yet have the cortical capacity to regulate that emotional response. This is traditionally likened to driving a race car without fully functioning breaks.

Hormones and neurotransmitters

Contributing to this perfect storm is a deluge of hormones and neurotransmitters that floods the adolescent's system. The influx of sex hormones during puberty facilitates the neurobiological changes occurring during this time. Sex hormones such as estrogen and testosterone enhance neuroplasticity and facilitate important developmental shifts in white matter, grey matter and limbic structures.

Adolescents also experience significant increases in key neurotransmitters such as dopamine and serotonin. Levels of dopamine, which contribute to experiences of pleasure, are higher during adolescence than at any other developmental period. The adolescent brain is virtually flooded with these pleasure-seeking chemicals. With its overpopulation of dopamine receptors, the nucleus accumbens is more active than the pFC when compared with other developmental periods. This is a significant contributing factor to the increase in sensation-seeking and risk-taking behaviors during adolescence and what makes substance use during this time especially impactful, according to a 2008 article in *Pharmacology, Biochemistry and Behavior* by Fulton Crews and his colleagues.

Sex hormones also influence the production of neurotransmitters. Estrogen increases the production of both dopamine and serotonin receptors. Estrogen, and to some degree testosterone, also boosts production of oxytocin, our "tend and befriend" hormone. This increase is thought to influence social connection and shift how we process and remember social cues.

During adolescence, the hypothalamic–pituitary–adrenal (HPA) axis, which helps regulate stress, also undergoes a second critical developmental period (the first being in infancy), according to Cheryl McCormick in a 2007 article in *Pharmacology, Biochemistry and Behavior*. Consequently, adolescents experience higher levels of cortisol in response to

stress, including social stressors. This means that chronic or acute stress can profoundly affect one's ability to self-regulate and cope with stress as an adult.

Given the surge of estrogen in girls and the fact that estrogen boosts HPA activity, girls have an increased response of the HPA axis to stress with advancing puberty. Boys, however, experience decreased HPA activity, possibly associated with increased testosterone. Therefore, on average, girls respond more strongly to psychological and social stressors, which may prime girls to be more susceptible to mood disorders. On the other hand boys, with lower HPA activity, tend to experiment more with drugs and other risk-taking behaviors.

Social consequences for adolescents

During this time, adolescents transition from a world in which their parents are central social figures to peers fulfilling that role. In a 2014 article in *Annual Review of Psychology*, Sarah-Jayne Blakemore suggested that adolescence represents a significant period in the development of social understanding because changes in the brain cause greater sensitivity to social cues. Not only do adolescents begin developing a sense of self-consciousness, but they also begin perceiving social cues differently from children and adults.

In a 2009 article in the *Journal of the American Academy of Child & Adolescent Psychiatry*, Abigail Baird and her colleagues examined how adolescents and adults perceive facial expressions differently. Adolescent participants frequently perceived more emotions incorrectly and showed more activity in the amygdala than did adults. In a 2003 article in *NeuroImage*, Christopher Monk and colleagues discussed how adolescents, unlike adults, have difficulty switching attention between different information in social situations and accessing limbic areas of their brain even when instructed to focus on nonemotional components of faces such as nose width.

On a neurological basis, the answer to the question of how technology may affect both the brain and behavior of adolescents is not yet clear. However, in a 2014 article in *Computers in Human Behavior*, Yalda Uhls suggested that tweens who went without technology (television, computers and mobile phones) for five days significantly improved their ability to read nonverbal emotion cues compared with peers who had regular access to technology. Adolescents are also neurologically more sensitive to social rejection and ostracism than children or adults, suggesting that adolescent bullying can profoundly affect both emotional well-being and brain development. Consequently, the *social* bullying more common among girls and the *physical* bullying more common among boys can lead to long-lasting struggles well into adulthood. Although bullying is clearly not beneficial, some social struggles that tweens and teens face are functional and necessary, according to Baird, who discussed the parenting implications of the teenage brain in a 2013 interview (see *pages.vassar.edu/abigailbaird/2013/11/19/the-teenage-brain/*).

All of our clients exist within a social context, but these systemic factors and related attempts to become functional participants in this world independently from caregivers influence continuing brain development in adolescence. According to Sonia Lupien in a 2009 article in *Nature Reviews Neuroscience*, adolescence is also a time when the effects of early life stress, such as rearing in low socioeconomic status environments or having depressed parents, start to become evident.

Neurocounseling with adolescents

As the brain continues to mature, adolescents begin to self-regulate, neurologically and intentionally. In doing so, they adaptively moderate their own emotions, enhance their perceptions of social cues, more accurately weigh information in making decisions and ultimately become more balanced and integrated. Although counselors cannot fast-forward brain development, nor would it be adaptive to do so, we can play a key role in shaping the development of the adolescent brain and supporting adolescents and caregivers throughout the process. What follows are some considerations for working with adolescents, their families and schools.

1) First and foremost, have a basic understanding of what is going on neurologically and how boys and girls can differ. The old adage that *knowledge is power* is very true in this context and can help adolescents better understand their experiences. Have discussions about times when clients experienced difficulty reading emotions, reacting too quickly or feeling ostracized, and then relate that back to their brain. Discuss how dopamine is soaring through their bodies and how they are primed to desire pleasure. Explain, especially to adolescent girls, how they may be more sensitive and react more emotionally to stress. By doing this, you are having adolescents think through how their emotions affect their decisions and reactions and beginning to foster connections with cortical areas of their brain.

2) Engage caregivers in psychoeducation, perhaps by inviting them to watch Baird's video. This will encourage understanding and prevent stigmatization, while also providing brain-based suggestions on parenting adolescents, such as why shame is so toxic, how behavioral approaches are beneficial and the differences in parenting girls and boys.

3) Pay attention to your own facial expressions and have discussions with clients about their perceptions of your nonverbal expressions and emotions. This can enhance social processing and provide corrective experiences for emotional awareness. Actively involving caregivers in these discussions with their children outside of session may also be helpful, as can having adolescent clients journal about their emotion responses to daily life.

4) Approaches that focus on emotions and behaviors may have greater benefits than approaches that require higher order thinking and perspective taking. Having your clients describe the feelings (words) that they put with their physiological emotions (body sensations) can help to foster connections between limbic and cortical areas, integrate whole brain functioning and subsequently influence emotion regulation. With early adolescent clients, be intentional about reflecting both the content and emotion of their stories. This will also help to scaffold the links between these two experiences not only for the client's understanding but also for the client's brain. In schools, develop groups around emotional awareness and processing.

5) Sensorimotor activities that cultivate regulation of the autonomic nervous

system are also advantageous. Grounding and breathing exercises, mindfulness, biofeedback and neurofeedback have all been used to enhance optimal brain development among adolescents. Mindfulness can even be used in school settings using curriculums such as Patricia Broderick's *Learning to BREATHE.*

6) Diet is another important issue for counselors. Recent research provides clear evidence that microbes in the gut directly influence the functioning of the autonomic nervous system, and adolescence is a critical period in how this gut-brain connection influences later mental health. For instance, probiotics can alter stress responses and promote neurogenesis. It is important to ensure quality nutrition during this time. This can be a tricky process with adolescents who adore pizza and soda.

7) Physical exercise also enhances neuroplasticity and optimal brain functioning. Ensuring that adolescent clients are getting plenty of exercise can enhance not only their brain development but also the work you are doing with them in the counseling room. For example, encourage clients to step away from technology, engage in physical activity and add probiotic-rich yogurt to their breakfast. First, however, consult physicians regarding diet and exercise specific to adolescents' unique needs.

8) Advocacy and social justice are also important systemic interventions to enhance adolescent brain development. For example, knowing that bullying and oppression (social ostracism) can profoundly affect the brains of adolescents, it is important for counselors to work to eradicate such systemic problems.

Conclusion

Often stigmatized as a time of reactivity, impulsivity and unyielding defiance, adolescence also represents a time of opportunity, both behaviorally and neurologically. Counselors can be a part of encouraging optimal brain development and possibly alleviating or even counteracting adverse effects of earlier developmental struggles. Much attention has been paid to the optimal brain development of young children, yet adolescence represents a second critical period that deserves equal focus and attention by neuroscientists and counselors alike. As with all clients, the importance and consequences of bridging brain and behavior during this "hazardous time" cannot be overstated.

Lori Russell-Chapin and Laura K. Jones serve as co-editors of the Neurocounseling: Bridging Brain and Behavior column. Contact them with comments, questions about neurocounseling or ideas for future columns at *lar@fsmail.bradley.edu* or *Laura.Jones@unco.edu.* ◆

Laura K. Jones is an assistant professor of applied psychology and counselor education at the University of Northern Colorado in Greeley. Contact her at *Laura.Jones@unco.edu.*

Letters to the editor: *ct@counseling.org*