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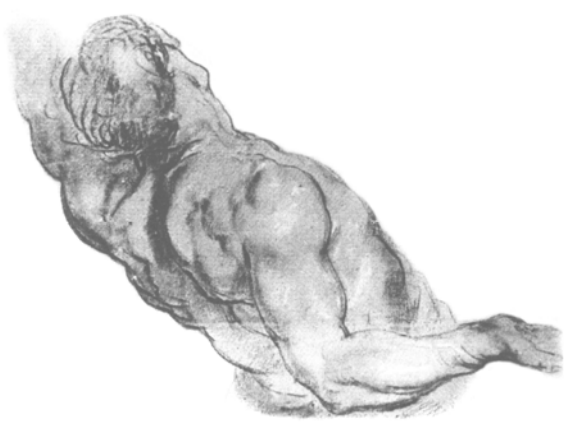

USABP Mission Statement
The USABP believes that integration of the body and the mind is essential to effective psychotherapy, and to that end its mission is to develop and advance the art, science, and practice of body psychotherapy in a professional, ethical, and caring manner in order to promote the health and welfare of humani

Part 1. The Adolescent Brain: A Decade of Research

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Abstract
A fundamental assumption of somatic psychology is that the mind and body are not separate but function as one (Reich, 1973). Contemporary theory and research in various scientific disciplines have contributed to our understanding of how the mind and body develop and function together within the evolving self. In particular, principles and findings in the field of neuroscience are increasingly being incorporated into psychology and inform clinical work. Until recently, little was known about the adolescent brain. However, the discovery of complex patterns of growth and change leading up to and continuing throughout adolescence has begun to reshape views of adolescent development and provide new insights into behavior. This article will present an overview of a decade of research on the adolescent brain and examine the evidence for adolescence as a critical period. The implications are discussed. Part 2 in a subsequent issue will focus on clinical applications of the research.

Keywords
Neuroscience – Adolescent Brain – Critical Period – Adolescent Development

Within the field of psychology, infancy and early childhood have come to be recognized as *the* critical period for development. The early environment in which development takes place is understood to exert profound influence on the trajectory of future development and well-being of the individual. Within the field of neuroscience the pre and perinatal period is commonly recognized as the critical period for brain maturation. More specifically, the human brain growth spurt begins in utero during the third trimester and continues through the second year of life (Schore, 2001). Due, in part, to recognition of the importance of early brain development, much attention and considerable resources have been focused on infancy as a critical period, as well as on early intervention. In the last decade, discovery of a secondary growth spurt in the brain leading up to and continuing through adolescence may suggest a second such critical period, with far reaching implications (Giedd, 2003; Giedd et al., 1999).

Critical or Sensitive Periods

In general terms, a critical or sensitive period refers to a specific window of time in which certain experiences are required in order for an organism's potential to unfold. If the appropriate experiences are not provided, development will be compromised. Central to the concept of critical periods is that impairments will be irreversible or only partially reversible (Giedd, 2003; Pearce, 2002; Schore, 1994, 2003; Siegel, 1999; Steinberg, 2005).

In neuroscience terms, a critical period is associated with rapid growth, reorganization and differentiation within the brain and is characterized by the processes of dendritic and synaptic proliferation, experience-dependent neural pruning (parcellation), and myelination. The completion of myelination is generally associated with the end of a critical period.

Different brain structures and systems mature at different rates and within different time frames and therefore have different critical periods. A key aspect of a critical period is that it represents a specific "window of opportunity" that opens and closes according to a particular timetable. During critical periods the brain is thought to be particularly receptive to environmental influences. Because the brain appears to be primed for new learning yet susceptible to the affects of adverse stimuli, a hallmark of critical periods is that they represent a time of both increased opportunities and vulnerabilities (Giedd, 2003; Giedd, 2008; Pearce, 2002; Schore, 1994; Siegel, 1999; Steinberg, 2005).

The Adolescent Brain

Unexpected Discoveries

Until recently there was little interest in studying the adolescent brain because structural development was assumed to be largely complete (Frontline PBS, 2002; Giedd, 2004; Walsh, 2004). By age three all major fiber tracts in the brain are discernible, by age six the brain has reached 90-95% of adult size, and by age twelve it has reached its full volume (Giedd, 2008; Schore, 1994, 2001; Siegel, 1999). In addition, by around age twelve, formal operations thinking, the highest level of cognitive development as originally conceptualized by Piaget, has been achieved (Inhelder & Piaget, 1958; Keating, 2004). Mental development (such as new learning and increased cognitive abilities) was assumed to progress through new connections between neurons and more efficient processing due to progressive myelination rather than as a result of structural changes (Keating, 2004). It was widely believed that during adolescence all that was required was education and experience.

The discovery that revolutionized our understanding of the adolescent brain was, in fact, uncovered quite by accident. When neuroscientist and child psychiatrist Jay Giedd joined a project with the National Institute of Health (NIH) in Washington DC, it was with the intention of mapping the developing brains of children with psychiatric disorders. He began by first attempting to study normal brain development in children and found very little information available. In 1991, Giedd began the first long-term MRI brain scanning study of normal children and adolescents with the goal of establishing a baseline (Strauch, 2003; Wallis, 2004). When Giedd first noticed the numbers that indicated an unexpected increase in gray matter in the brain he thought it was an error—however, further examination revealed unexpected patterns of growth in a number of structures within the neocortex, most importantly the prefrontal cortex (Giedd et al., 1999). In 1999, Giedd and colleagues published findings that would generate a cascade of new research as well as burgoening interest in the adolescent brain within the scientific community and the general public alike.

Changes in Gray Matter Density During Adolescence

The first clue to the changes taking place in the adolescent brain was the discovery of a thickening in gray matter leading up to puberty (Giedd et al., 1999). The brain is made up of both gray and white matter. Gray matter consists of tightly packed neuron cell bodies and their branches (dendrites), while white matter consists of axons emanating from within gray matter that are coated in a fatty insulating substance called myelin. Previous studies using cross-sectional data had identified linear decreases in cortical gray matter between childhood and adulthood, accompanied by linear increases in white matter associated with neural maturation (myelination). (For a detailed list of these studies see Giedd et al., 1999). In contrast, utilizing longitudinal data Giedd and colleagues identified an overall thickening of cortical gray matter that peaked at around age eleven for girls and twelve for boys. The observed preadolescent increases in gray matter were followed by post-adolescent decreases. These findings were significant because the thickening of gray matter is generally associated with the proliferation of dendrites and synapses—in other words, processes that signal the onset of critical periods and the emergence of new capacities. Decreases in gray matter when associated with normal processes of selective pruning (parcellation) reflect the means by which new capacities are refined.

Further examination of the data by Giedd et al. (1999) revealed that the changes in gray matter were regionally specific. They found that growth in the parietal and frontal lobes peaked around age 12, while gray matter continued to increase in the temporal areas until age 16, and in the occipital lobes through age 20. This landmark study appeared to identify not only a previously unrecognized growth spurt but a complex pattern of synaptogenesis and parcellation—processes that parallel those previously thought to take place only during infancy. In the 1999 study, the authors conclude that “if the increase [in gray matter] is related to a second wave of overproduction of synapses, it *may* herald a critical stage of development when the environment or activities of the teenager may guide selective synapse elimination during adolescence” (p. 863)[italics added].

Greatest Changes Occur in the Frontal Lobes

Further research has confirmed the general pattern of gray matter changes observed in Giedd et al.’s original 1999 study (Paus, 2005; Sowell, Thompson, Holmes, Batth, et al., 1999; Sowell, Thompson, Holmes, Jernigan, et al., 1999; Sowell, Trauner, Gamst, & Jernigan, 2002). Sowell and colleagues observed a decrease in gray matter after puberty, with the greatest changes found in the frontal and parietal areas (Sowell, Thompson, Holmes, Batth, et. al., 1999). In a separate study using a broader age range, Sowell, Thompson, Holmes, Jernigan et al. (1999) hypothesized that differences in gray matter between adolescents (12-16) and adults (23-30) would be greatest in frontal regions of the brain because the capacities being developed during adolescence are consistent with maturation of the frontal lobes while capacities associated with other areas are largely mature by adolescence. As predicted, the parietal, temporal and occipital lobes showed little maturational change, whereas dorsal, medial and lateral regions of the frontal lobes showed large group differences.

In both of these studies, decreases in gray matter in frontal areas appeared to be related to increases in white matter. The authors suggest that the apparent loss of gray matter might be the result of myelination rather than the loss of tissue (neural pruning) (Sowell, Thompson, Holmes, Batth, et al., 1999; Sowell, Thompson, Holmes, Jernigan, et al., 1999). Nonetheless, Sowell and colleagues conclude that their findings support the notion that changes in specific brain structures are related to the development of specific capacities and highlight the potential importance of the frontal lobes to the development of adult cognition (Sowell, Thompson, Holmes, Jernigan, et al., 1999).

Subsequent studies have identified complex patterns of change in various regions of the adolescent brain (Barnea-Goraly, Menon, & Eckert, 2005; Casey, Giedd, & Thomas, 2000; Durston et al., 2001; Giedd, 2004; Paus, 2005; Paus et al., 1999; Sowell, Thompson, Holmes, Batth, et al., 1999; Rabinowicz, Petetot, Khoury & de Courten-Myers, 2009; Sowell et al., 2002; Suzuki et al., 2005; Thompson et al., 2000). For example, the caudate, a structure within the basal ganglia associated with mediating higher cognitive functions, attention and affective states, follows a similar pattern of preadolescent increases followed by decreases (Giedd, 2008). The hippocampus, central to memory storage and retrieval, increases in volume during adolescence in both females (Day, Chiu, & Hendren, 2006; Giedd et al. 1996; Sowell & Jernigan, 1998) and males (Suzuki et al., 2005). The amygdala, which assesses the salience of stimuli and influences the encoding of memory, increases during adolescence more significantly in males than in females (Giedd, 2008; Giedd et al., 1996). Differences between the sexes in amygdala and hippocampal changes have been attributed to the distribution of sex hormone receptors within these structures (Day, Chiu & Hendren, 2006; Durston et al., 2001; Giedd et al. 1996; Giedd, Shaw, & Wallace, 2006). Taken together, the anatomical studies reviewed above make it clear that the adolescent brain is not complete but very much a work in progress.

White Matter Changes During Adolescence

While the evidence suggests that cortical gray matter increases and then decreases (Giedd et al., 1999), recent studies, consistent with earlier research, have shown linear increases in overall cortical white matter during the transition from childhood to adulthood (Blakemore & Choudhurry, 2006; Giedd, 2003; Giedd, 2004; Giedd et al., 1999; Paus, 2005). Although white matter development is generally linear (increasing over time), studies have revealed that changes in white matter (like gray matter) are regionally specific (Barnea-Goraly et al., 2005; Benes, Turtle, Khan, & Farol, 1994; Paus, 2005; Thompson et al., 2000). Research suggests that frontal areas, particularly the lateral prefrontal cortex, are among the last brain regions to mature, with white matter increases continuing into the twenties (Casey et al., 2000; Giedd et al., 2006; Paus, 2005; Keating, 2004). The identified increases in white matter are significant because they reflect progressive myelination within and between various structures, creating faster, more efficient neural connections. On the other hand, myelination is associated with the locking in of developmental gains and a reduction in neural plasticity (Damasio, 1999; Pearce, 2002; Schore, 1994; Siegel, 1999). Full myelination of a circuit or module is associated with brain maturation and may signify the end of a sensitive or critical period.

White matter changes during adolescence have been identifed in a number of brain areas. For example, Thompson et al. (2000) report a pattern of rostro-caudal (front to back) growth in the corpus callosum, a major white matter structure that connects the left and right hemispheres of the brain. As Thompson et al. suggest, the integration of information from both hemispheres is considered essential for higher-level language and cognitive functioning, and continued growth in the callosal isthmus through age fifteen may reflect the fine-tuning of language skills that occurs later in childhood and early adolescence.

Benes and colleagues (1994) identified progressive myelination in the superior medullary lamina (SML) that continues through adolescence and into adulthood. The SML connects the cingulate gyrus (involved in emotional processing) with the hippocampus (necessary for transferring new memory into long-term memory)—in other words, the connection of emotional reactions with historical, contextual thought. Benes et al. speculate that as myelination of this pathway progresses, adolescents may become more capable of emotional regulation and impulse control, as well as develop in the direction of greater cognitive maturity (Benes et al., 1994; Benes interview in Strauch, 2003; Sowell & Jernigan, 1998). Benes and colleagues further note that myelination in the hippocampus occurs earlier in females than in males and may be relevant to gender differences in cognitive and emotional development (Benes et al., 1994).

In a recent study, Barnea-Goraly et al. (2005) found complex patterns of change in white matter density from childhood to adolescence in prefrontal regions, the internal capsule as well as basal ganglia and thalamic pathways, the ventral visual pathways and the corpus callosum. They conclude that there are significant changes in brain regions that are important for attention, motor skills, cognitive ability and memory. As Paus (2005) states, “Smooth flow of information throughout the brain depends to a great extent on the structural integrity and maturity of white-matter pathways” (p. 61). Taken together, the evidence suggests enhanced brain organization during adolescence through faster, more efficient connections within and between various regions of the brain (Keating, 2004; Paus, 2005; Steinberg, 2005).

The Development of Prefrontal Executive Functions and Interregional Interconnectivity

The research regarding gray and white matter changes reviewed above highlights two key aspects of adolescent brain maturation: first, that there is substantial development within multiple regions of the prefrontal cortex, and second, that there is increased connectivity throughout the brain due to progressive myelination (Benes et al., 1994; Keating, 2004; Luna et al., 2001, Paus, 2005, Paus et al., 1999; Sowell, Thompson, Holmes, Batth, et al., 1999; Sowell, Thompson, Holmes, Jernigan, et al., 1999; Thompson et al., 2000). While much attention has been focused on development of the prefrontal cortex because of its executive role in integrating and regulating various brain functions, it is important to note that these executive functions are made possible by expanding connections between the prefrontal cortex and other parts of the brain. It appears that these developments allow for greater integration, more complex processing, and as a result, the emergence of new capacities.

Shades of Gray: The Debate about the Meaning of Relative Gray to White Matter Changes

While there is general agreement about the broad patterns of gray and white matter changes over the course of adolescence, the meaning of those changes is less clear (Casey et al., 2000; Durston et al., 2001; Paus, 2005; Sowell, Thompson, Holmes, Batth, et al., 1999; Sowell, Thompson, Holmes, Jernigan, et al., 1999; Sowell et al., 2002). Scientists debate whether the loss of gray matter represents neural pruning or simply the coating of gray matter with myelin. To the layperson this is a subtle distinction, but it is an important one because it speaks to the issue of adolescence as a critical period. Synaptic pruning or parcellation is thought to be experience-dependent while it is not known whether myelination is influenced by environmental factors.

A classic series of post-mortem studies suggest that synapse elimination (neural pruning) does in fact take place during adolescence (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997), while increasing myelination at the border between gray and white matter may also contribute to observed cortical thinning (Giedd et al., 2006). It seems reasonable to conclude that both processes may be occurring. The fact that gray matter changes are non-linear (gray matter increases before decreasing) and regionally specific (Blakemore & Choudhury, 2006; Giedd et al., 1999; Paus, 2005) provides the strongest evidence for adolescence as a critical period. As Giedd (2008) states, “The powerful process of overproduction followed by selective/competition elimination that shapes the developing nervous system *in utero* seems to continue to refine the brain throughout adolescent development” (p. 340).

While most neuroscientists would agree that genetically driven brain development during adolescence is associated with the emergence of new capacities, they do not necessarily agree on the degree to which adolescent brain development is influenced by the environment (Deerin, 2001; Vedatam, 2001). It may be that the development of some structures and systems are driven primarily by genetics, while others are shaped by experience. For example, twin studies suggest that the cerebellum, which undergoes a major growth spurt in adolescence, is highly influenced by the environment, while the corpus callosum is not (Giedd, 2004; Giedd, 2008). Both theory and research suggest that maturation of the prefrontal cortex is experience-dependent (Casey et al., 2000; Schore 1994, 2001a), and it has been suggested that the relatively late and prolonged developmental processes in the frontal lobes may render them particularly susceptible to environmental influences (Casey et al., 2000; Pearce, 2002; Schore, 2001; Siegel, 1999). The degree to which the development of various structures and systems are genetically driven or influenced by environmental influences remains an open question. The intersection between genetics and experience and the timing of potentially critical periods is of particular importance to those studying the origins of various psychopathologies with the goal of designing potential interventions. A great deal of research is being conducted in this area, which will continue to be an important avenue of investigation. For an overview of the current literature on neuroimaging and psychopahthology see Giedd et al. (2006) or Toga, Thompson, & Sowell (2006).

The issue of adolescence as a critical period is an important one. If adolescence reflects a second critical period (or more accurately a series of critical periods), it suggests far greater neural plasticity than previously recognized. Such neural plasticity has profound implications for our ongoing capacity for growth and change. Whether or not decreases in gray matter reflect neural pruning, ongoing structural changes suggest a major reorganization of various structures and systems in the brain during adolescence, along with their associated functions.

The Role of the Prefrontal Cortex

Changes occur throughout the brain during adolescence. However, some of the most dramatic and significant changes appear to occur in the frontal lobes (Barnea-Goraly et al., 2005; Giedd, et al., 1999; Paus, 2005; Sowell, Thompson, Holmes, Jernigan, et al., 1999). The frontal lobes have been implicated in many important functions including: aspects of working memory, the allocation of attention, the capacity for self-regulation, the integration of thought and emotion, the ability to connect past, present and future, the evaluation of potential risks and rewards, response inhibition, and the ability to produce socially appropriate behavior (Casey et al., 2000; Damasio, 1999; Giedd, 2004; Keating, 2004; Schore, 1994, 2001; Siegel, 1999). Most higher order cognitive capacities such as language, abstract thinking, logical reasoning and decision-making, plus the abilities to organize, prioritize and plan have been linked to the frontal lobes (Keating, 2004; Spear, 2008; Steinberg, 2005). Keating (2004) suggests that evidence supports the view of the prefrontal cortex as “a more general synthesizer of experience and governor of action” (p. 49).

The prefrontal cortex has garnered great interest from the scientific community and the general public, perhaps because of its potential for explaining some of the more challenging aspects of adolescent behavior. Characteristics commonly associated with adolescence such as emotional volatility, impulsivity, difficulty planning or envisioning consequences, as well as increased risk taking, may be due in part to incomplete maturation of the prefrontal cortex.

The Relationship Between Structure and Function

While it is difficult to relate structural changes in the adolescent brain directly to specific cognitive advances or behaviors, a growing number of studies demonstrate that the brains of adolescents function in ways that are fundamentally different from those of adults. For example, a study by Baird, Yurgelen-Todd and colleagues suggests that adolescents and adults process emotional expression differently (Baird et al., 1999; Spinks, n.d.; Yurgelen-Todd interviewed in Strauch, 2003). In a task requiring participants to view images of faces and identify emotions, fMRI brain scans showed that in children and adolescents the amygdala became highly activated when viewing frightened faces, while frontal areas were more active in adults. The amygdala is associated with instinctive or “gut reactions” such as fight, flight or freeze, while frontal areas allow for more complex processing, the ability to make subtler distinctions between emotions, and the capacity to respond with enhanced judgment. The brain scans also showed that as teens got older, activity shifted from the amygdala towards the prefrontal cortex. These findings suggest that children and younger adolescents may react from parts of the brain primed for fear and alarm because frontal areas are not yet fully developed. In addition, children and adolescents tended to make more errors, mistaking fearful expressions for other emotions such as shock, anger or confusion (Baird et al., 1999). A more recent study further confirms that different brain areas are recruited in the processing of fearful facial expressions in adolescence and adulthood, with adults showing greater connectivity between the amygdala and the hippocampus (central to the formation, storage and processing of memory) than adolescents (Guyer et al., 2008). Such differences in emotional processing may help to explain some of the reactivity associated with adolescence, as well as emotionally charged conflicts that sometimes erupt between adolescents and their parents or peers.

Additional studies also provide evidence that as the brain matures and reorganizes, it processes information differently. In another study, McGivern, Andersen, Byrd, Mutter, and Reilly (2002) examined the potential influence of synaptic proliferation in the frontal lobes on cognition. They found that at age 11 or 12 (around the onset of puberty), the speed at which children could match images of faces with the appropriate emotion dropped significantly from the previous year. Reaction times became more efficient over the next two to three years, stabilizing by age 15. McGivern et al. concluded that changes in reaction time could reflect the relative inefficiency of prefrontal circuitry as the adolescent brain undergoes its growth spurt and pruning. These finding are consistent with the idea that temporary disorganization may precede reorganization.

Relevant to the issue of impulse control, a study by Luna et al. (2001) suggests that cognitive controls over behavior develop progressively from childhood to adulthood. They found that the ability to perform a simple response-suppression task improved gradually through childhood and adolescence. (A response supression task examines the ability to voluntarily supress a specified behavior, in this study, eye movement.) While adolescents were able to perform the task at the same level as adults, they recruited different brain systems in order to do so. Adolescents showed substantially more activity in the dorsolateral prefrontal cortex (associated with controlled, effortful processes), while adult responses reflected integrated function of a number of different brain areas including the neocortex, striatum, thalamus and cerebellum. Keating (2004) notes that the findings by Luna et al. (2001) are “consistent with the notion of a complex assembly of mechanisms of conscious control during the adolescent transition, which leads to more automatic and less effortful governance by the prefrontal cortex with maturity” (p. 71). The studies detailed above point to the importance of ongoing development of prefrontal executive functions during adolescence as a foundation for more efficient, flexible and integrated processing in adulthood.

Neurophysiological Changes in Adolescence.

While adolescent behaviors such as emotional reactivity, impulsivity, and risk-taking may be explained in part by the limitations of an immature prefrontal cortex, other changes have been implicated as well. Adolescence involves the reorganization of multiple brain and body systems, and while some aspects of development may proceed relatively independently, others appear to interact. For example, cognitive development (associated with maturation of the prefrontal cortex) appears to proceed on schedule even in the event of late or early puberty, while other brain processes (and resulting behavioral changes) appear to be influenced by the influx of hormones associated with the onset of puberty (Dahl, 2004; Keating, 2004; Nelson et al., 2002; Spear, 2000; Steinberg, 2005).

Animal studies suggest that increased levels of gonadal and adrenal hormones associated with puberty directly impact the balance of neurotransmitters throughout the brain (including norepinephrine, dopamine and serotonin) which regulate mood and excitability, as well as act upon motivation and reward systems within the brain (Cameron, 2004; Spear, 2000). In addition, sex hormones appear to be particularly active within the emotional limbic system—a high number of androgen (male hormone) receptors are located in the amygdala, while the hippocampus has a greater number of estrogen (female hormone) receptors (Casey et al., 2000). Neurophysiological changes that occur with the onset of puberty have been implicated in a number of adolescent behaviors including mood fluctuations, changes in drives (including romantic and sexual interest), sleep patterns, increased novelty seeking, sensation-seeking and risk taking, as well as gender differences in behavior (Carskadon, Acebo, & Oskar, 2004; Compas, 2004; Dahl, 2004; Spear, 2000; Steinberg, 2004, 2005; Strauch, 2003; Wallis, 2004; Walsh, 2004).

Changes in Dopamine and Motivational Systems: Adaptation and Risk

Spear (2000) describes alterations in the dopamine system during adolescence that may have important consequences for behavior. More specifically, there is cross-species evidence that while the amount of input from the excitatory neurotransmitter glutamate and the inhibitory neurotransmitter gamma-amino-butyric acid (GABA) decrease in prefrontal areas during adolescence, dopamine levels peak in the prefrontal cortex and limbic regions during this period. Dopamine is involved in the pleasure and reward system of the brain and the positive feelings induced by increased levels of dopamine tend to reinforce behavior (and therefore learning). Dopamine is known to increase when we encounter novel stimuli.

While dopamine levels decline overall between childhood and adulthood, higher dopamine levels in adolescents as compared with adults may prime teens for exploration and enhance learning. The picture is not a simple one, however. While dopamine increases in the prefrontal cortex and limbic regions during adolescence, it decreases in the nucleus accumbens and other parts of the reward system. This suggests that adolescents as a group may be dopamine-depleted and therefore might seek more stimulating activities in order to get the same effect (Spear interview in Strauch, 2003; Steinberg, 2004). In a similar vein, data from a recent study by Bjork et al. (2004) suggests that the nucleus accumbens, central to motivation, may not be fully developed in adolescents, and as a result they may seek either highly stimulating activities or ones that require minimal effort (Bjork et al., 2004; Wallis, 2004). Whether as a result of excess dopamine in frontal and limbic areas, or as a result of decreases in the motivation-reward system, changes in the dopamine system are implicated in increased exploration, sensation-seeking and risk-taking behaviors. Spear (2000) further states, “To the extent that adolescence is associated with developmental alterations in prefrontal cortex, limbic brain areas, and the dopamine input to these regions, concomitant developmental alterations in various motivated behaviors might also be expected” (p. 113).

Spear (2000, 2008) emphasizes the adaptive aspects of increased exploration and risk-taking in the transition to adulthood. Such behaviors may serve an evolutionary function that supports the attainment of skills necessary for independence. She notes that behaviors such as novelty-seeking, risk-taking, increased social investigation and interaction with peers can be observed in adolescents of many species. According to Spear, peer-directed social interactions may be important to the development of new social skills, help guide choice behaviors such as food selection (for better or worse), and provide opportunities for practicing and modeling adult behaviors. In addition, it is typically in adolescence that the young of various species begin to expand their range of exploration. The benefit from an evolutionary perspective is the dispersal of offspring to new territories before they begin to mate which helps to avoid inbreeding. Spear (2000, 2008) observes that research suggests adolescents who engage in moderate risk-taking behaviors tend to be more socially competent in both childhood and adolescence than abstainers or high risk takers. She concludes that some adolescent risk-taking and sensation seeking appears to be normative across a variety of species.

From an evolutionary perspective, the neurophysiological changes associated with puberty appear to prime the organism for physical growth, exploration, and learning new skills and behaviors necessary for survival. Although changes in the brain may be evolutionarily adaptive, there are increased risks as well. In addition to increases in sensation-seeking and risk taking, Spear and others note that changes in frontal areas, limbic circuits and the dopamine system, along with social factors, may make adolescents particularly susceptible to the addictive effects of substances such as nicotine, drugs and alcohol (Chambers, Taylor, & Potenza, 2003; Jackson, 2005; Spear, 2000; Strauch, 2003; Walsh, 2004).

Implications

The Gap between Emotional Development and Cognitive Controls

In recent years, neuroscientists have begun to trace the development of various structures and systems within the adolescence brain. The relationship between those changes and changes in behavior remain largely speculative, however. Nonetheless, several themes have emerged that suggest specific aspects of adolescent brain development that may contribute to both increased vulnerabilities and opportunities during this period.

First of all, cross-species evidence suggests that neurophysiological changes associated with puberty appear to “rev up” the system, making it more excitable, emotionally reactive and susceptible to stressors (Dahl, 2004; Spear, 2000). As Dahl (2004) describes, neuroendocrine changes that impact limbic and motivational regions of the brain may create a “natural tinderbox” (p. 20) of igniting passions in which certain types of feelings may be triggered more quickly and with greater intensity than during childhood or adulthood. In addition, theses changes appear to create the tendency to *seek* experiences that create intensity, excitement and arousal (thus the youth battle cry of “sex, drugs and rock and roll!”).

While neurophysiological changes that appear to fire up the system begin with the onset of puberty, research suggests that development of prefrontal executive functions—including the capacities for impulse control, logical reasoning, planning and the ability to consider the consequence of actions—occurs later, with maturation proceeding gradually over the course of adolescence and continuing long after puberty is complete (Dahl, 2004; Giedd et al., 1999; Keating, 2004; McGivern et al., 2002; Paus, 2005). The fact that the prefrontal cortex matures late allows for greater flexibility (neural plasticity) and therefore the ability to adapt to the demands of a particular environment. However, the asynchrony between early emotional and motivational changes and later development of prefrontal regulatory capacities creates a potential disjunction between an adolescent’s emotional experience and his or her ability to regulate thoughts, feelings, drives and behavior (Dahl, 2004; Steinberg, 2004, 2005). This potential gap suggests increased risks for a broad range of emotional and behavioral problems.

The gap between emotional processes and the development of cognitive controls may be exacerbated by a recent trend towards earlier pubertal maturation (Dahl, 2004). A number of studies conducted in Western industrialized societies have documented a decline in the average age of pubertal onset over the past century, particularly for girls (Rutter, 1993 cited in Dahl, 2004; Papalia, Olds, & Feldman, 2007; Pearce, 2002). Whether due to improvements in nutrition and medical care, or less benevolent causes such as the use of hormones in food production or exposure to highly-sexualized environments, earlier puberty appears to set in motion neurobehavioral changes such as sexual interest, sensation-seeking and risk-taking. While changes in motivational and emotional processes are occurring at earlier ages, there is no concomitant change in cognitive development. There is a strong body of evidence that suggests cognitive development proceeds independently and is associated with age and experience rather than pubertal timing (Dahl, 2004; Keating, 2004; Steinberg, 2004, 2005).

At a time when emotions run high and judgement and self-control are not fully developed, adolescents are confronted by an increasingly complex world. In tribal societies, the onset of puberty is often accompanied by initiation rites that mark the beginning of a sort of tutelage by village elders. In addition, within many traditional societies, most adolescents live and work alongside parents, extended family or community members as they prepare for clearly defined adult roles (Sisson, Hersen, & Van Hasselt, 1987). In contrast, within contemporary industrialized societies, adolescents tend to be isolated together as a group, with greater “freedoms,” and less supervision or participation by responsible adults (Hersch, 1998; Hine, 1999). Although modern society offers a wide array of opportunities in terms of lifestyle, education and occupation, adolescents today are faced with an onslaught of situations for which they may not be ready (from being manipulated by marketers or posting provocative photos on a personal web page, to a range of potentially unprotected sexual experiences, greater access to alcohol, drugs and even weapons). Greater recognition that adolescents’ emotions and desires precede their ability to manage them speaks to the importance of ongoing support and guidance during this transitional period.

The Central Theme of Adolescent Brain Development—Integration

Mental development occurs throughout the lifespan. However, there are certain critical periods—*windows of opportunity*—during which the brain is more malleable and primed for growth and new learning. A growing body of evidence suggests that adolescence is just such a critical period. Although the rate and magnitude of changes are far greater in infancy than in adolescence (Day et al., 2006), the developmental processes of synaptic growth and neural pruning appear to be the same (Giedd, 2008). If adolescence represents a critical period for brain maturation, then what is it critical for? In infancy, it is the right hemispheric emotional system and self-regulatory capacities that are undergoing critical periods of maturation (Schore, 1994, 2000, 2001, 2003; Siegel, 1999). During adolescence, the central theme of brain development is *integration.*

The literature has focused much attention on prefrontal executive functions because of their role in impulse control. The emphasis has been on *vertical integration*: inhibitory control of the prefrontal cortex over the lower limbic circuits responsible for automatic emotional responses. While vertical integration is important (particularly in light of changes in limbic and motivational systems that appear to make adolescents more prone to impulsivity and risk taking), changes in the brain during adolescence allow for integration at many levels. It is significant to note that many of the brain areas that undergo substantial changes during adolescence serve important integrative functions. For example, the basal ganglia help to prioritize information from various brain systems en route to the frontal lobes and to organize a behavioral response (Giedd, 2003). The corpus callosum which connects the two hemispheres of the brain allows for the integration of two distinct modes of processing—the sequential, analytical mode of the left, with the more intuitive, holistic right (Siegel, 1999; Thompson et al., 2000). This integration across the two hemispheres can be described as *lateral or horizontal integration*. The cerebellum with its intricate connections to the neocortex may also connect the two hemispheres indirectly, as well as playing a role in integrating various aspects of affective and cognitive experience with movement and therefore behavior (Damasio, 1999; Siegel, 1999). Overall, greater interregional connectivity and development of the prefrontal cortex as a synethesizer of experience, appears to allow for more complex processing, greater integration and the emergence of new capacities, as well as new ways of experiencing and being in the world. In simple terms, "*The whole is greater than the sum of its parts."*

Integration supports optimal functioning. The brain is composed of various structures and systems that specialize in processing different types of information. As Siegel (1999) describes, the way in which the different circuits function and interact give rise to the quality of our subjective experience from moment to moment. Various systems within the brain may act cooperatively, conflict or remain disconnected from one another. Cohesive states, in which the various modes of processing are integrated are the most functional and adaptive (Cozolino, 2002; Levine, 1997; Schore, 1994 2003; Siegel, 1999). Integration supports the smooth flow of information between various brain systems allowing for more flexible responses to the environment or the task at hand. As Siegel suggests, "The integration of these distinct modes of information processing into a coherent whole may be a central goal for the developing mind across the lifespan"(p. 4). It is important to note that the processes by which the brain becomes more integrated appear to be at their peak during adolescence.

Integration is a source of tremendous creativity. To use a metaphor, in the Western musical scale there are only seven notes. However, through novel arrangements between those notes a seemingly infinite number of possible melodies and unique modes of expression can arise. In a similar manner, it is through the integration of various neural systems that thought and emotion, intellect and instinct can be harmonized to generate not only the widest (and perhaps *wisest*) range of choices within any given situation, but create a sense of wholeness as well. The development of a cohesive sense of self or *identity* is recognized as a central task of adolescence (Blos, 1967, 1978; Erikson, 1968, 1985; Gemelli, 1996; Sisson et al., 1987).

Much attention has been focused on the risks and vulnerabilities of adolescence. What we have failed to adequately address, however, is its potential. Processes of integration likely underlie what Keating (2004) refers to as the assembly of an "advanced executive suite of capabilities" that allows for the "attainment of a more fully conscious, self-directed, and self-regulating mind" (p. 48). The expanding abilities of adolescents to further differentiate self from others, to think abstractly, reason, generate creative solutions to problems, and take broader perspectives are essential to successful adult functioning. More importantly, the capacities developing during adolescence, in particular the capacity for self-reflection, are the very capacities that make lifelong growth and change possible.

In summary, neuroscience research over the last decade indicates that brain development is more prolonged than previously recognized. Growing evidence for adolescence as a critical period suggests increased vulnerabilities, as well as unique opportunities to support developing capacities. The unexpected discovery that brain development continues throughout adolescence and beyond provides a salient reminder that our children's needs are ongoing. It is important that as a society we invest resources in ways that continue to support development at every age.

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Biography

Deborah Harkin, Ph.D. earned a doctorate in Clinical Psychology with a specialty in Somatic Psychology at Santa Barbara Graduate Institute (SBGI) in 2007. Her dissertation synthesized traditional psychoanalytic theories of adolescent development, attachment theory and recent discoveries in neuroscience on the adolescent brain. She is currently a core faculty member at SBGI and can be reached at dharkin@thechicagoschool.edu.

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How does material in this manuscript inform the field and add to the body of knowledge? If it is a description of what we already know, is there some unique nugget or gem the reader can store away or hold onto? If it is a case study, is there a balance among the elements, i.e, back ground information, description of prescribed interventions and how they work, outcomes that add to our body of knowledge? If this is a reflective piece, does it tie together elements in the field to create a new perspective? Given that the field does not easily lend itself to controlled studies and statistics, if the manuscript submitted presents such, is the analysis forced or is it something other than it purports to be?

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