Neurobehavioral Changes in Adolescence

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Abstract

Adolescents across a variety of species exhibit age-specific behavioral characteristics that may have evolved to help them attain the necessary skills for independence. These adolescent-related characteristics, such as an increase in risk taking, may be promoted less by the hormonal changes of puberty than by developmental events occurring in brain. Among the prominent brain transformations of adolescence are alterations in the prefrontal cortex, limbic brain areas, and their dopamine input, systems that are sensitive to stressors and form part of the neural circuitry modulating the motivational value of drugs and other reinforcing stimuli. Such developmental transformations of the adolescent brain may predispose adolescents to behave in particular ways and make them particularly likely to initiate use of alcohol and other drugs.

Keywords

adolescent; adolescence; brain development; risk taking; drug use

To successfully negotiate the developmental transition from youth to maturity, adolescents of many species must survive the risks and stressors of this disequilibrating passage while acquiring the skills necessary for independence and success in adult life. Although certain attributes of human adolescents are unique and not evident in other species, other characteristic features are expressed by adolescents of diverse species and may be evolutionarily adaptive in helping the adolescent conquer this critical transition. For instance, like their counterparts among human adolescents, rats undergoing the developmental transition of adolescence likewise show a marked developmental increase in the amount of time spent in social investigation and interaction with peers, along with elevations in risk-taking behavior, illustrated by their seeking out novel stimuli and exploring unknown areas more avidly than at younger ages or in adulthood. Although some adolescent-associated increase in risk taking and sensation seeking appears normative across a variety of species, there may be individual differences in the expression of these propensities within species. High levels of risk taking may be maladaptive, leading to excessive use of drugs and alcohol by some human adolescents or their involvement in reckless activities that may be life-threatening for themselves or others.

One of the prominent physiological events occurring at some point within the broad age range of adolescence is a pubertal increase in sex hormones (e.g., estrogen in females and testosterone in males) and the associated emergence of secondary sexual characteristics. Yet, there is surprisingly little evidence that these hormonal alterations are associated in any simple fashion with behavioral change during adolescence (Susman et al., 1987). Instead, striking changes that occur in the adolescent brain may contribute to the behavioral changes characteristic of this age. Brain areas undergoing remodeling during adolescence in a variety of species include stressor-sensitive forebrain regions implicated in novelty seeking and in modulating the motivational value of drugs and other reinforcing stimuli. Given the clear differences between adolescents and adults in functioning of these brain regions, it would be surprising indeed if adolescents did not differ from adults in various aspects of their behavior toward these stimuli.

ADOLESCENT-TYPICAL BEHAVIORS AND RESPONSES TO STRESSORS

Social Interactions and Peer Affiliations

Social interactions, particularly with peers, take on increasing importance during adolescence in many species. Human adolescents spend substantially more time interacting socially with peers than with adults; peer-directed social interactions may help the adolescent develop social skills away from the home environment and hence ease the transition toward independence (Larson & Richards, 1994). In many species, social interactions also help guide choice behavior, such as selection of appropriate food items, and provide the opportunity to practice and model adult-typical behavior patterns (Galef, 1981).

Sensation Seeking and Risk Taking

Adolescents across a variety of species exhibit age-related increases in novelty seeking, sensation seeking, and risk taking (Arnett, 1992; Spear, in press). This may have evolutionary significance in providing the impetus to explore novel and broader areas away from the home, helping to avoid inbreeding via dispersal of male (and sometimes female) offspring to new territories away from the initial social unit before they reproduce. Such increases in risk taking may also provide the opportunity to explore new behaviors and potential rewards, perhaps facilitating the relinquishing of childhood patterns of behavior as well as the acquisition of behaviors essential for successful adult functioning.

The kinds of risks that human adolescents take include not only reckless behavior, school misconduct, and so-called antisocial behaviors (including fighting, stealing, trespassing, and property damage), but also use of alcohol, cigarettes, and illicit drugs. Shedler and Block (1990) have argued that modest amounts of risk taking may represent "developmentally appropriate experimentation," noting that, for instance, adolescents engaging in moderate extents of risk taking have been found to be more socially competent in both childhood and adolescence than abstainers as well as frequent risk takers. Thus, although there may be constructive functions of risk taking—at least in an evolutionary sense and arguably also for the individual human adolescent—excess may be disadvantageous, if not life-threatening, for the adolescent or others.

Adolescent Drug Use

As with other types of risk-taking behavior, some amount of exploratory drug use is normative in human adolescents. According to the 1996 survey results from the Monitoring the Future Study, sponsored by the National Institute of Drug Abuse, by the time that adolescents reach their senior year in high school, approximately 50% have used marijuana or hashish, 65% have smoked cigarettes, and 82% have drunk alcohol (Johnston, O'Malley, & Bachman, 1998). This drug use begins relatively early in adolescence, with 26% of 8th graders reporting use of alcohol and 15% reporting use of illicit drugs in the prior month. Some of this use is excessive. For instance, 10% of 8th graders, 21% of 10th graders, and 31% of 12th graders reported getting drunk one or more times during the past month. Clearly, many adolescents engage in at least some exploratory drug use, with evidence of excessive use emerging in some individuals.

Consequences of such use may be long-lasting. Early onset of drug and alcohol use is one of the strongest predictors of later abuse of alcohol and other drugs (Grant & Dawson, 1997). It remains to be determined whether early drug use serves merely as a marker of later abuse or whether such drug exposure is causal, influencing ongoing brain development to induce long-term alterations in neural function that increase later propensity for drug abuse.

Stress and Adolescence

Studies examining adolescents of a variety of species have shown that adolescents may be more disrupted by stressors than adults are. Although most human adolescents traverse this developmental period without significant psychological problems, the incidence of depressed mood is greater during adolescence than at younger or older ages (Petersen et al., 1993). Adolescents may generally respond with greater negative affect to circumstances in their environment than do children and adults; even when referring to the same activities, adolescents often find them less pleasurable than their parents (Larson & Richards, 1994).

Physiologically as well, adolescents may show an increased responsivity to stressors. Human adolescents exhibit greater increases in blood pressure and in blood flow through the heart in response to various laboratory test procedures than do children (Allen & Matthews, 1997). Similarly, in other species, adolescents often exhibit elevated stress-induced increases in the stress-related hormone corticosterone relative to younger organisms and prolonged increases in corticosterone relative to adults (Spear, in press). Such elevated stress responsivity of adolescents may contribute to their propensity to initiate drug and alcohol use, given that stressors have been shown to enhance alcohol consumption and to facilitate the onset of drug use.

THE ADOLESCENT BRAIN

More dramatic than the often-striking changes occurring in the physical appearance of adolescents are the transformations that are occurring in their brains. This remodeling of the brain is seen in adolescents of a variety of species and entails not only brain growth, including the formation of additional connections between nerve cells, but also a prominent loss (or pruning) of such connections in particular neural regions. Among the brain areas prominently remodeled during adolescence is the prefrontal cortex, a brain region thought to be involved in various goal-directed behaviors (including rule learning, working memory, and spatial learning) and in emotional processing, particularly of aversive stimuli. Along with a decline in the relative size of the prefrontal cortex during adolescence, there is substantial remodeling of connections between neurons—with some connections lost and others added.

As can be seen in Figure 1, the amount of input received from two key chemicals (neurotransmitters) involved in brain-cell communication—the excitatory neurotransmitter glutamate and the inhibitory neurotransmitter gamma-aminobutyric acid (GABA)—is reduced in prefrontal cortex during adolescence, while input from another neurotransmitter, dopamine, peaks in prefrontal cortex during adolescence (Lewis, 1997). Developmental adjustments in dopamine activity are evident not only in prefrontal cortex, but also in limbic brain regions (Andersen, Dumont, & Teicher, 1997). A variety of other adolescent-associated neural alterations are seen across species in various limbic brain regions. For example, Yurgelun-Todd, at the McLean Hospital in Belmont, Massachusetts, has found an age-related shift in activation of the human amygdala, a limbic structure that, among other things, is thought to be involved in emotional reactivity and in coordinating responses to stressful stimuli.

The adolescent-associated changes in dopamine input to prefrontal cortex and limbic brain regions may be of considerable consequence for adolescent behavior and psychological functioning. This stress-sensitive dopamine system appears to play a role in novelty seeking (Dellu, Piazza, Mayo, Le Moal, & Simon, 1996) and to be part of the neural circuitry involved in assessing the motivational value of stimuli, including potentially reinforcing drugs, and translating this assessment into action (Kalivas, Churchill, & Klitenick, 1993). 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. Alterations in the incentive value attributed to stimuli could underlie many of the behavioral alterations seen in adolescents, increasing the importance of social reinforcement derived from peers and provoking the pursuit of new potentially rewarding stimuli, a quest that may lead to increases in drug use and other risk-taking behaviors. Given the differences between adolescents and adults in functioning in these brain regions, it would be astonishing indeed if adolescents did *not* differ from adults in various aspects of their motivated behavior.

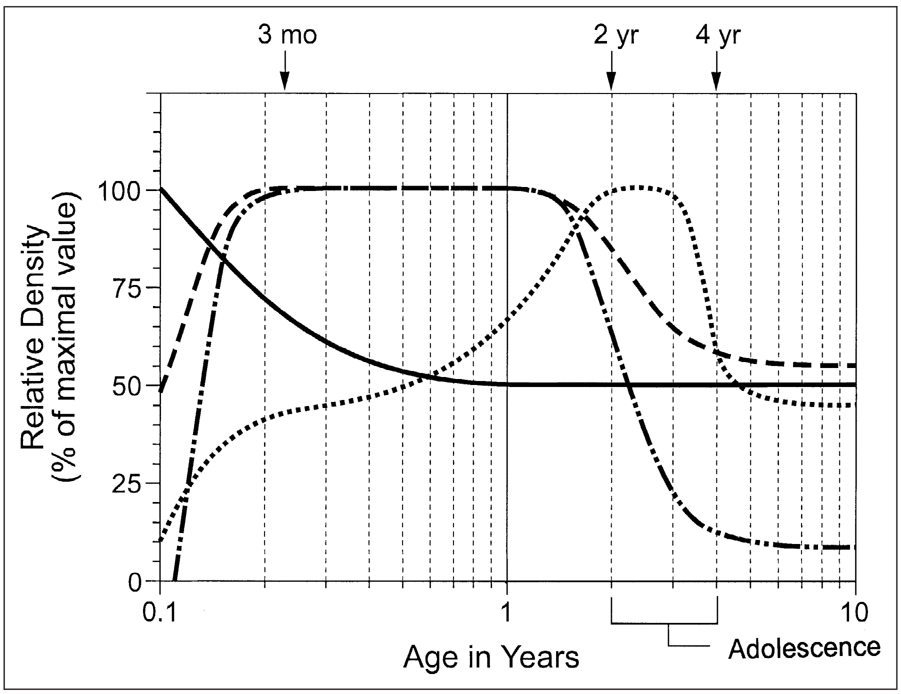

Fig. 1. Age-related changes in four types of input to a major type of output neuron (layer III pyramidal cells) of the primate prefrontal cortex. The *x*-axis refers to the age of the animals, and the *y*-axis represents the percentage of the maximal value reached at any point in the life span for each measure. The broken line illustrates excitatory glutaminergic input into this cortical region, the broken line with dots shows gamma-aminobutyric acid (GABA) inhibitory input, and the dotted line illustrates dopamine input; the solid line demonstrates levels of another neurotransmitter (cholecystokinin) in this brain region. Reprinted by permission of Elsevier Science from "Development of the Prefrontal Cortex During Adolescence: Insights Into Vulnerable Neural Circuits in Schizophrenia," by D.A. Lewis, 1997, *Neuropsychopharmacology*, *16*, p. 392. Copyright 1997 by American College of Neuropsychopharmacology.

FINAL THOUGHTS

Over the past several decades, research in developmental psychology has placed surprisingly little emphasis on the adolescent brain in the quest for determinants of adolescents' typical behavioral propensities. But the focus of research is gradually changing, with the recognition that the brain of the adolescent differs markedly from the younger or adult brain, and that some of these differences are found in neural regions implicated in the typical behavioral characteristics of the adolescent. Yet, much remains to be done.

Additional research is needed to examine normal brain function in adolescence. The rather piecemeal observations of the adolescent brain to date need to be integrated within a broader characterization of adolescent brain function. Then, the relationship of these neural alterations to adolescent-typical behavior patterns needs to be substantiated using experimental approaches.

Neural mechanisms underlying initiation of drug use during adolescence are a particularly important area for study. Given the clear differences between adolescents and adults in brain regions implicated in drug seeking and other motivated behaviors, the factors that serve to precipitate and maintain adolescent drug and alcohol use may well vary from the factors that underlie such use in adulthood. Yet, study of psychobiological determinants of drug initiation has been almost exclusively conducted in adult organisms, so the findings are of questionable relevance to the typical initiation of alcohol and drug use during adolescence.

The question also remains as to whether early exposure to drugs or alcohol actually increases the propensity for later abuse, or whether early use is just a marker for a later abuse disorder. This issue is clearly germane to current prevention efforts directed toward postponing first use ("just say later").

Multiple research approaches and study populations will be needed in this work. Although some aspects of adolescence can be properly and productively modeled in laboratory animals, others clearly cannot and will require studies in human adolescents. Advances in brain-imaging techniques (Thatcher, Lyon, Rumsey, & Krasnegor, 1996) have made the brain of the human adolescent more accessible for study, yet many questions about the adolescent brain and its relationship to age-related behavioral characteristics will require experimental manipulations involving laboratory animals. Multidisciplinary studies conducted in species ranging from human and nonhuman primates to rodents and using levels of analysis ranging from gene expression to behavior will help illuminate the dramatic transformations of the adolescent brain and their association with behavioral function during this unique maturational phase.

Recommended Reading

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Note

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