Adolescent Brain Development: A Period of Vulnerabilities and Opportunities

Keynote Address

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ABSTRACT: This article introduces and summarizes the goals of the symposium. It also provides an overview of a conceptual framework for understanding adolescence, which emphasizes how the very nature of this developmental transition requires an interdisciplinary approach—one that focuses on brain/behavior/social-context *interactions* during this important maturational period. More specifically it describes a set of neurobehavioral changes that appear to be linked to pubertal development, which appear to have a significant effect on motivation and emotion, and considers these puberty-specific changes in affect in relation to a much larger set of developmental changes in adolescence. This framework is used to argue for the need for a transdisciplinary dialogue that brings together work in several areas of neuroscience (including animal models) and normal development with clinical and social policy research aimed at early intervention and prevention strategies.

KEYWORDS: adolescence; puberty; neuroplasticity; high-risk behavior; interdiciplinary studies

INTRODUCTION AND GOALS

One of my first goals in this opening address is to try to convey some of the excitement that has been generated among the organizers of this conference—Linda Spear, Ann Kelley, Dick Clayton, Rashid Shaikh, and myself—in the months of planning that led up to this meeting. In part, this enthusiasm emerged directly from the prospects of hearing about and discussing the many rapid advances that will allow us to gain greater understanding of the development of the adolsecent brain. Even further, we were excited at the prospect of bringing together investigators from a wide range of backgrounds and scientific disciplines in order to *create a broader interdisciplinary dialogue*.

This, we believe, is one of the key issues for the field: stronger scientific bridges need to be built across disciplines that will allow previously separate bodies of knowledge to be linked and more effectively applied to the large-scale problems af-

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fecting youth. It is essential, we believe, not only to deepen our understanding of specific neurobiological changes during adolescent development, but also to broaden our knowledge of how behavioral, familial, and social influences *interact,* in multifaceted ways, with the development of the biological systems of interest.

The stakes are high: the problems affecting adolescents in our society are both enormous and complex. On one hand, there are reasons to be optimistic about the prospects of contributions from current and future scientific advances in these areas: We are entering a period of rapid progress in research aimed at many aspects of adolescent development, including several areas of basic and clinical research. These studies are beginning to provide new insights about adolescence as a unique developmental period. These include normal developmental studies of cognitive, emotional, and social maturation in adolescence; clinical research focusing on the development of a broad range of behavioral, emotional, and substance abuse problems in adolescence; and advances in using animal models to understand both neural and behavioral aspects of development during puberty and adolescence. In addition, many conceptual and methodological advances have been made in studies of adults—including rapid progress in cognitive and affective neuroscience as well as the use of structural and functional neuroimaging tools and molecular and genetic methods—that can now be applied to questions about adolescent maturation. Several of these areas of investigation are creating invaluable contributions that have direct relevance to understanding a variety of dimensions of adolescent development. There is every reason to predict that the rapid growth in many of these fields will continue to accelerate.

On the other hand, rapid growth along several different lines of investigation introduces new challenges as well as opportunities. A key part of the difficulty in this field is the tendency toward fragmentation—insularity within disciplines working on related and somewhat overlapping areas of investigation. There is often a shortage of effective bridges between disciplines: Stronger links need to be forged between animal and human investigations of adolescence, and developmental and clinical approaches need to be better integrated, as do biological and social frameworks, for understanding adolescent development. More generally, we need to promote *trans*disciplinary dialogues as well as better conceptual integration of many of the separate lines of investigation.

This is, in many ways, the *primary goal* of this conference (and a key goal for this *Annals* volume as well as its eBriefing on the Academy's web site <http://www.nyas.org/ebriefreps/main.asp?intSectionID=189>). We seek to establish connections—scientifically, conceptually, and through personal relationships—that will help counteract the tendency towards insularity within disciplines.

This emphasis on integrating a diversity of scientific backgrounds began at the level of the organizing committee for the conference, which included individuals from basic and behavioral neuroscience, clinical research in pediatrics and child psychiatry, and the social sciences and prevention research. We have attempted to organize this symposium in ways that are consistent with this trans-disciplinary goal, as will be seen in the eight sessions reported here. The format for each section includes an introduction by the organizer who selected each presenter for that session, followed by two or three papers that juxtapose basic research with other more clinical or social approaches, followed by a discussant who provides some integration of the different papers or points to particular lines of research needed to advance future understanding.

We believe that promoting such trans-disciplinary dialogue represents a crucial step toward the long-term goal of achieving a deeper understanding of adolescence as a unique period of development. In this opening address I want to sketch a conceptual framework for adolescence that emphasizes how the very nature of this developmental transition requires an interdisciplinary approach. I wish to underscore how a set of neurobehavioral changes at puberty represents *part* of a much larger set of maturational changes in adolescence, and how these require an approach that focuses on brain/behavior/social-context *interactions* during this important maturational period.

FRAMING THE BIG QUESTIONS: THE HEALTH PARADOX OF ADOLESCENCE

Adolescence presents a striking paradox with respect to overall health statistics. This developmental period is marked by rapid increases in physical and mental capabilities. By adolescence, individuals have matured beyond the frailties of childhood, but have not yet begun any of the declines of adult aging. Compared to young children, adolescents are stronger, bigger, and faster, and are achieving maturational improvements in reaction time, reasoning abilities, immune function, and the capacity to withstand cold, heat, injury, and physical stress. In almost every measurable domain, this is *a developmental period of strength and resilience*.

Yet, despite these robust maturational improvements in several domains, overall morbidity and mortality rates *increase* 200% over the same interval of time. This doubling in rates of death and disability from the period of early school age into late adolescence and early adulthood is not the result of cancer, heart disease, or mysterious infections. Rather, the major sources of death and disability in adolescence are related to *difficulties in the control of behavior and emotion*. It is the high rates of accidents, suicide, homicide, depression, alcohol and substance abuse, violence, reckless behaviors, eating disorders, and health problems related to risky sexual behaviors that are killing many youth in our society. These problems are documented as frequently in the popular media as they are in the medical or epidemiologic literature. Adolescence is strongly associated with an increase in risk-taking, sensation-seeking, and reckless behavior—all of which which lead, far too often, to actions with dire health consequences.

These high rates of "reckless" behavior in adolescence also highlight a second level of paradox: In most measurable ways, adolescents have developed *better* reasoning capabilities and decision-making skills than children. Older teenagers can perform at (or very near to) adult levels in their abilities to understand, cognitively, the consequences of risky behavior. Adolescents are much better than children at the mental processes that underpin making logical and responsible choices. Yet, despite these cognitive improvements, adolescents appear to be more prone to erratic—and, as I will argue, *emotionally influenced*—behavior, which can lead to periodic disregard for the risks and consequences.

These striking paradoxes—high rates of morbidity and mortality despite robust physical health, and increasing rates of reckless behavior despite improved capacities for decision making—provide part of the framework regarding the importance of research into the neurobehavioral underpinnings of these developmental changes.

Compelling scientific questions lurk within these mysteries and seeming contradictions. Achieving a deeper understanding of adolescent neurobehavioral development can, in the long run, contribute to the pragmatic goals of early intervention to address these large-scale problems.

ACKNOWLEDGING THE COMPLEXITY OF THE PROBLEMS

On one hand, there are compelling reasons to believe that neuroscientific research can ultimately help to delineate underlying developmental processes in ways that can inform more effective early interventions and social policies to promote healthier adolescence. On the other hand, there are equally compelling reasons to believe that complex behavioral and social factors are so intertwined with biological development as to make simplistic or reductionist goals untenable.

Examining neurobehavioral contributions in the developmental pathways leading toward these problems does *not* equate to a reductionistic approach; the goal is not to try to reduce those complex problems to the level of brain mechanisms or biological interventions. Investigators working in basic research in these areas must collaborate closely with their colleagues in clinical and social sciences. And for their part, the clinical and social scientists must seek collaboration with basic scientists without fearing that a mechanistic understanding of some aspects of these problems implies any diminished role for the social, cultural, and familial influences on these developing biological systems. Rather, it is important to emphasize how a mechanistic understanding of biological processes can actually *enhance* the importance of behavioral or social policy interventions.

To provide a simple example of this principle of collaboration between both ends of the scientific spectrum, consider the effect of scientific progress in understanding the biologic mechanisms contributing to genetic vulnerability to skin cancer. This set of insights about biological processes has not led to "blaming" the problem on the genes *or* ignoring the role of behavior and context (i.e., the role of excessive sun exposure and sunburn leading to skin cancer). Instead, mechanistic understanding of how fair-skinned children are at high risk for ultra-violet skin damage has *promoted* adaptive behavior: parents of fair-skinned children are now more highly motivated to use sunscreen and protective clothing for these children to prevent the biological vulnerability (genetically low levels of melanin in the skin) from leading to skin cancer in adulthood.

A second example—a bit closer to our focus on brain development— is the "0 to 3" campaign that has raised awareness about the importance of brain development in the first few years of life. This emphasis on biological processes has *not* been reductionistic, and has not been viewed this way by policy makers. Evidence of brain plasticity in the early years of life has not led to the conclusion that parenting and social experience are unimportant during this maturational period, but rather to its opposite: Developmental psychologists, neuroscientists, and policy makers are more likely to emphasize the value of social policies that protect and support infants and toddlers during this important period of brain development. There are, I believe, parallel opportunities regarding interdisciplinary approaches focusing on puberty and adolescent brain development.

I believe that these are crucial issues for our field. Basic neuroscientists, developmental psychologists, clinical investigators, and social scientists must work together to understand adolescence. A conceptual framework must be constructed that emphasizes the *interactions* of brain, behavior, and social context in the developmental pathways to positive and negative outcomes in youth. We need to examine, scientifically, specific components of these processes, without forgetting the complex nature of the problems.

WHY IS ADOLESCENCE A TIME OF SO MANY COMPLEX PROBLEMS?

Part of the problem of adolescent tendencies toward irrational, emotionally influenced behavior has been recognized throughout human history. As Aristotle noted more than twenty centuries ago:

> Youth are heated by Nature as drunken men by wine.

Or, in Shakespeare's words:

> I would that there were no age between 10 and 23, for there's nothing in between but getting wenches with child, wronging the ancientry, stealing, fighting… *(The Winter's Tale,* Act III*)*

Yet, there are also important differences in how we can approach understanding adolescents' problems in contemporary times. Today we can begin to parse these complex problems into empirical questions about adolescent development. We can now move beyond age-old observations and negative characterizations of impulsive and "hot-headed" youth, and start to ask specific scientific questions: What is the empirical evidence that adolescents are "heated by Nature"? Are these changes rooted in biology? Are some of these changes simply a function of greater freedoms and social influences? Are there neurobehavioral underpinnings to some of these adolescent tendencies that are universal across cultures? Are some of these changes related directly to increases in specific hormones? Are they linked to maturational changes in specific neural systems in adolescence? Which aspects of these developmental changes and problems can be modeled in animal studies? Are there unique types of neural "plasticity" during puberty and adolescence, when a particular set of individual experiences can have longstanding effects on the trajectory of development? How do these periods of plasticity create *vulnerabilities* that in turn contribute to the high rate of serious problems and disorders emerging in adolescence? How might this same type of plasticity create unique *opportunities* to intervene in positive ways at this point of development?

An analogy can illustrate the key principle: Consider the natural developmental window for learning fluency in a second (or third) language. While, a person *can* learn a new language at any age, the process of becoming easily fluent in a new language changes significantly after puberty. For an adult to achieve an even modest level of proficiency in a new language requires a great deal of motivation, special training, drills, persistent efforts, and an enormous amount of time. It is also exceedingly difficult to speak without a strong accent for persons who have learned a language as an adult. In contrast, during childhood and early adolescence, a simple immersion in an environment with a new language can result in mastery with little

or no formal teaching, and a gradual loss of an identifiable accent. (A good example of this is the contrast between Henry Kissinger, who came to the U.S. as an 15-year-old, and his brother, who was 3 years younger when the family moved to this country. His brother speaks English without a noticeable accent, while Kissinger, a brilliant man who has developed a masterful command of the English language, speaks with a heavy accent and retains a consistent set of speech patterns that identify him as someone who did not learn this language during the optimal developmental window.)

This concept of *plasticity* in underlying neural systems forms the basis of several crucial questions regarding puberty and adolescence—and in ways that are likely to have great clinical relevance. For example, is there an analogous natural window of plasticity for learning *emotional* regulation? Is there a developmental period when an individual can—with the right kinds of experience—easily achieve social and emotional fluency? And if something prevents or interferes with this emotional learning process during this natural period of development, is it fundamentally more difficult to achieve such refined or fluent control at a later point?

Human and animal studies are being conducted that are providing empirical data to address questions about the unique opportunities in this interval of development. The findings are likely to have enormous implications about clinical and social policy regarding the impact of early interventions. The pay-off for interventions that are implemented before these windows of plasticity become narrowed, or closed, may be much greater than the same interventions provided later in adulthood (when the underlying neural systems may be slower to adapt to change). We are at a very early point in the curve of scientific understanding of these complex issues, but a great deal of evidence exists that points toward unique opportunities, and vulnerabilities, that emerge in adolescence.

A PERIOD OF STORM AND STRESS?

Nearly 100 years ago, the pioneering psychologist G.S. Hall performed a body of work that began the modern study of adolescence. His work emphasized this developmental interval as a period of "heightened storm and stress," a phrase that has long been an influential metaphor for understanding adolescence. In the 1960s and '70s attempts were made to understand these problems in terms of "raging hormones." Those early investigations contributed some understanding of the role of pubertal hormones in some adolescent behavioral and emotional changes, but it also became clear that many models of these hormonal effects were overly simplistic. Pubertal hormones do not seem to *cause* behavioral problems or emotional turmoil: many of the youth with the highest levels of these hormones showed little or no problems with stress, emotions, or behavior.

J.J. Arnett[1] wrote a thoughtful review of these issues in 1999, asking what the empirical evidence is regarding stress, hormones, and puberty. His review provides a nice counterweight to many oversimplified views of these complex issues. First, many, and perhaps most, adolescents navigate this transition with minimal difficulties. Perhaps up to 80% of youth have little or no major problems during these "tumultuous" times. Arnett's paper, along with other influential papers by Steinberg *et al.* and Masten *et al.* (1999) over the past decade, reminds us to be careful not to

over-generalize the (sometimes) dramatic problems in some adolescents. In fact, most adolescents get along quite well with their parents and teachers most of the time, succeed in school, have positive relationships with peers, do not become addicted to drugs or alcohol, and become productive and healthy adults. However, there is also evidence that a significant proportion of adolescents *do* experience great stress, struggle, and emotional turmoil. As stated earlier, this developmental period shows a sharp increase in morbidity and mortality related to a wide range of types of behavioral and emotional problems. In addition, it is also a time when trajectories are set (or altered) in ways that lead to difficulties in adulthood. Adolescence often contains the developmental roots of lifetime problems with nicotine dependence, alcohol and drug use, poor health habits, relationship difficulties, and failure to develop skills and knowledge leading to a productive job or career. Trajectories are set in adolescence that can have a major impact later in life, and there are reasons to believe that altering these trajectories in positive ways prior to adulthood can have a larger scale effect than the same intervention applied later in the lifespan.

A NATURAL TENDENCY TOWARD RISK TAKING, SENSATION SEEKING, AND STRONG EMOTIONS?

Part of the vulnerability (and opportunity) in this period of development may be linked to a set of biologically based changes in neural systems of emotion and motivation, which contribute to what appears to be a natural increase in tendencies toward risk taking, sensation seeking, and some emotional/motivational changes during pubertal maturation. On one hand, these appear to be normative changes that affect most adolescents to some degree; on the other hand, in some individuals and in some social contexts, these normative tendencies can lead to serious problems—as will be discussed in greater depth as this book unfolds.

It is valuable, therefore, to examine and better understand the neurobehavioral underpinnings of these normative affective changes, which may represent more than just simply adolescent brooding, moodiness, and romantic inclinations. There seems to be a natural biologic proclivity toward high-intensity feelings that emerges at puberty. Some emotional states—specific types of feelings—may be triggered more quickly and/or with greater intensity as a function of the biological changes attendent on pubertal maturation. For example, the tendency for increased parental conflict in early adolescence can be understood, at least in part, in relation to an increase in the *intensity* of emotion that is aroused during pubertal maturation.[2]

There is a second, somewhat related, set of observations about adolescent emotional development. Pubertal maturation is associated with a greater inclination to *seek* experiences that create high-intensity feelings. For example, studies of sensation seeking—a measure of how much an individual *wants* to experience risks, thrills, excitement, and intensity—reveal a similar developmental increase that is linked to puberty.[3]

Adolescents *like* intensity, excitement, and arousal. They are drawn to music videos that shock and bombard the senses. Teenagers flock to horror and slasher movies. They dominate queues waiting to ride the high-adrenaline rides at amusement parks. Adolescence is a time when sex, drugs, *very* loud music, and other high-stimulation experiences take on great appeal. It is a developmental period when an appe-

tite for adventure, a predilection for risks, and a desire for novelty and thrills seem to reach naturally high levels.

While these patterns of emotional changes at puberty are evident to some degree in most adolescents, it is also important to acknowledge the wide range of individual differences during this period of development. For some adolescents this tendency to activate strong emotions and an affinity for excitement can be subtle and easily managed. In others, these inclinations toward high-intensity feelings can lead to emotionally charged and reckless adolescent behaviors, and at times to impulsive decisions by (seemingly) intelligent youth that are completely outrageous.

ADOLESCENT EMOTIONAL BEHAVIOR: AN ILLUSTRATIVE ANECDOTE

A young guy scanning the crowd at a party notices a girl who he finds strikingly attractive. Immediately smitten, he approaches her and launches a shower of compliments. She tries to rebuff his flattery but finds something about the young man quite appealing. Romantic feelings kindle quickly. As he departs, with a kiss followed by a second kiss, emotions are flaring.

On the basis of one brief meeting, a conversation of less than a hundred words, and two kisses, the emotional lives of two adolescents have been turned upside-down. Each cannot stop thinking about the other. These two are obsessed with a desire to meet again. They manage a clandestine late-night rendezvous. Passionate feelings now accelerate at a feverish pitch. Their motivation to be together quickly rises above all competing priorities. They are willing to spurn friends and family, disregard dangers, ignore pain, and begin to act as if being together is more important than life itself—though they just met four days previously and barely know each other.

If evaluated by a psychiatrist who did not understand youthful passions, these two could easily be judged as meeting diagnostic criteria for serious mental disorders or cognitive impairments. Previously learned abilities to think logically and behave rationally seem to have evaporated in a matter of hours. When viewed with a sense of emotional detachment—without some feeling for the heat and power of young love—this scenario of adolescent behavior would appear simply ludicrous.

Yet the story of *Romeo and Juliet* has moved audiences to tears for centuries. The basic elements of the story date back to the Greek novelist, Xenophon. An Italian version of the story written in 1535 by Luigi da Porto placed the scene in Verona and named the feuding families Montecchi and Capellati. Then followed an English poem by Arthur Brooke in 1562 titled *The Tragical History of Romeus and Juliet.* But it was Shakespeare's adaptation in 1595 that made this tale what is probably now the most successful drama in history.

This story of two adolescents in love has evoked sympathetic responses across many translations and cultures because of a nearly universal human appreciation for the emotional intensity—and potential for tragedy—from rapidly igniting adolescent passions. It is also illuminating to reflect on Juliet's age: in the Luigi da Porto's version, Juliet (Giuletta) was 18 years old and the courtship developed over a few weeks. In contrast Shakespeare made Juliet only 13 years old and he compressed the action into four days.

One can only speculate why Shakespeare created a heroine so young in this romantic tragedy. It seems likely that for dramatic effect he intentionally juxtaposed adult-like passions with the naïveté of a very young teenager. As a shrewd observer of human nature Shakespeare recognized early adolescence as a time of life that creates a natural tinderbox for igniting passions.

So the emotional changes in adolescence have been generally recognized for many centuries. But over the past 50 years studies in developmental psychology have added considerable scientific substance to our knowledge of adolescent cognitive and emotional development. And, most recently, the tools of modern neuroscience as well as the use of animal models are empowering an even deeper understanding of this developmental period.[9] These advances are generating new insights into some of the roots of emotional, motivational, and behavioral changes that emerge at puberty. However, before turning to address some of these findings, it is first necessary to consider some broader questions about how we should best conceptualize, and *define,* adolescence.

WHAT *IS* ADOLESCENCE?

Adolescence has been defined in different ways by different groups of investigators and it is sometimes difficult to reach any convergence of opinion. This lack of clear definition becomes ever more challenging when attempting to bridge between animal and human models of puberty and adolescence. Yet, these are crucial issues for our field. In part, the difficulties reaching a clear consensus are related to ambiguities regarding how best to *conceptualize* the notion of adolescence. Other contributors to this symposium will present several perspectives on these issues.

I will begin this discussion by offering some opinions, including a definition that our research group has found useful, along with a brief introduction of a conceptual model of adolescence—one that reflects the work of our NIMH-supported interdisciplinary research network called ADAPT (Adolescent Development Affect-Regulation and the Pubertal Transition Research Network). Our research group[2] presents a more detailed account of this model and its relevance to using affective neuroscience to investigate the developmental psychopathology emerging in adolescence.

Let us then provisionally define adolescence in humans as *that awkward period between sexual maturation and the attainment of adult roles and responsibilities.* This defintion has proven useful in several ways. It captures the concept that adolescence begins with the physical/biological changes related to puberty, but it ends in the domain of social roles. It encompasses the transition from the social status of a child (who requires adult monitoring) to that of an adult (who is him- or herself responsible for behavior).

In other words, the end of adolescence and onset of adulthood cannot be understood solely on the basis of physical changes. To illustrate this point, consider the maturational classification of a girl, like Juliet, who is physically mature in every measurable way—fully grown in height, adult bone age, adult levels of hormones, sexually and reproductively mature, and highly intelligent, but who is 13 years old and in 7th grade. No one would argue that this individual should be considered an adult. Being an adult is not simply a matter of completing a certain category of phys-

ical development—it involves attaining a broader set of skills and knowledge that is part of the larger process of taking on adult roles and responsibilities.

Adolescence involves transitions in social roles (from that of a child to that of an adult) interposed with a multitude of pubertal changes in body and brain. Thus, it is optimal to have a working definition of adolescence that is consistent with a conceptualization of adolescence, which is, by its very nature, best understood at the level of *interactions* between biological, behavioral, and social domains.

Since, in this conceptualization, adolescence begins in the domain of physical changes (puberty) but ends in the domain of social context (adult roles), efforts to understand the transition period *must* entail interdisciplinary approaches. The very nature of this transition involves interactions between the biological, behavioral, and social domains. Understanding this transition will therefore require conceptual and methodological approaches that reflect the cross-disciplinary nature of the problem. While many scientific investigations will perforce focus on specific aspects or components of adolescence, it is equally important to place these elements within the framework of this larger perspective.

THE ONSET OF ADOLESCENCE: BIOLOGICAL CHANGES OF PUBERTY

One place to begin within the complex suite of maturational processes that we call adolescence is to focus on the biologic changes that occur at puberty. These are striking in several ways: First, puberty brings dramatic changes in body size and composition (including alterations in muscle and fat, as well as increased rate of growth and metabolic rate). Second, puberty leads to the physical changes of sexual maturation—breast or phallic development and the development of secondary sexual characteristics, including pubic and axillary hair, skin and odor changes, and deepening of the voice and development of facial and body hair in boys. Third, the physical changes of puberty lead directly to alterations in many aspects of social experience. The world treats an individual differently when he or she begins to look like an adult. (A fourth domain of changes—cognitive, psychological, and emotional changes linked to puberty—will be discussed later.)

Thus there are several interrelated processes that contribute to the physical, emotional, and social changes that are encompassed by physical maturation. Even within this relatively narrow focus on physical changes at puberty (within the much broader set of developmental changes that stretch across adolescence) it is clear that there are still several component processes that can be considered separately. At least three sets of pubertal changes can be linked to specific sets of hormonal changes. For example, rapid physical growth and increased height is strongly linked to changes in growth hormone (GH) and the upstream neuroendocrine changes that result in very high rates of GH secretion in mid-puberty (with some added contribution by sex hormones).

In contrast, a second neuroendocrine axis, which leads to the *gonadarche*, works through the pulsing of gonadotrophins, which ultimately causes the onset of phallic or breast development at puberty. Gonadarche begins with the pulsing of gonadotrophin-releasing hormone (GnRH) in the hypothalamus of the brain, which stimulates the pituitary to release the hormones LH and FSH into the blood, where

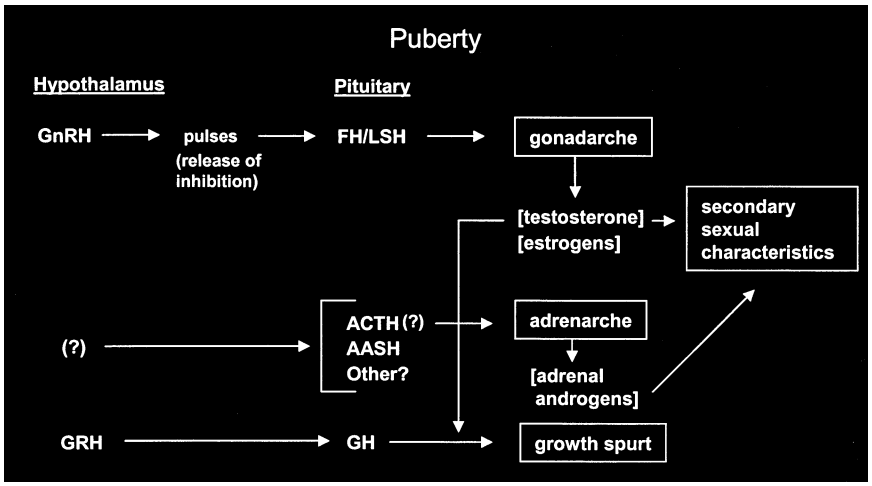

FIGURE 1. The neuroendocrine aspects of puberty include three components: gonadarche, adrenarche, and the pubertal growth spurt.

they then continue the cascade of changes by stimulating the gonads. Once the gonads are activated by LH/FSH, there is a sharp increases in estrogen in females and testosterone in males.The rising level of estrogen causes breast development in the female and the rising levels of testosterone lead to phallic growth, increased muscle mass, and voice changes in the male.

A third neuroendocrine axis, which leads to *adrenarche*, involves hormones released by the adrenal gland, including DHEA and DHEAS. These hormones often begin to rise by 6–9 years of age, but continue to increase throughout adolescence and typically peak in the early 20s. These adrenal hormones are often considered "weak" versions of sex hormones, and they bind to different receptors in the body, which contributes to adolescent changes in skin (e.g. acne) and the development of pubic and axillary hair (FIG. 1).

Clearly, puberty is *not* one process—it is a suite of changes that occur in relative synchrony. Moreover, as is apparent to those who have worked in a pediatric endocrine clinic, there is not only a wide range of variations in the precise sequence and timing of these various components, but also many types of disorders that can result in turning on a single component within this complex system. For example, some individuals can show premature adrenarche without any other sign of puberty; in other cases a girl may show premature breast development without any other sign of pubertal or adrenarchal maturation, while in some cases an individual may show an extremely early but otherwise normal spectrum of all elements of precocious puberty. Most importantly, these pubertal changes are only one set of maturational processes within the broader scope of adolescence, which includes the development of cognitive, emotional, and social skills and knowledge, as well as the maturation of judgment.

SOME ASPECTS OF ADOLESCENT DEVELOPMENT HAVE BEEN OCCURRING EARLIER

It is crucial to consider the various components of adolescence because there have been recent historical changes in the timing of (at least some aspects) of development, there now being an earlier onset of pubertal processes, particularly in females. FIGURE 2 provides data summarized by Rutter and colleagues[4] showing a great deal of historical evidence for changes in the *average* age of pubertal onset over the past century.

As shown, the age of menarche in Finland, Sweden, Norway, Italy, the UK and the United States between 1860 to 1960 has increased fairly markedly. (It is important to note here that menarche is a relatively *late* event in female puberty.) Individuals are usually at Tanner Stage 4 by the time menarche occurs, so the biological cascade has begun years earlier. Thus, when we talk about adolescence, we're not just talking about teenage years, but about this interval that often begins with a cascade of hormone changes by 9–12 years of age, with most of the physical changes of puberty often complete by the middle of the teen age years.

FIGURE 3 shows some more recent data in the U.S. on the early start of pubertal maturation. This study by Herman-Giddens and colleagues examinined a representative sample of 17,000 girls in pediatric practices. FIGURE 3 shows the number of girls at age 7 and 8 years of age that were at Tanner Stage 2 or above in breast or pubic hair development. It shows that by 7 years of age 7 % of European American, and 27% of African American, were already at Tanner 2—a stage that the level of estrogens or adrenal androgens had caused the body to develop breast tissue and/or pubic hair. By 8 years of age 47% of the African American girls were at Tanner 2! Therefore, when we talk about adolescence as an interval of development that begins with pubertal maturation, it is quite misleading to use the common convention of interchanging the word "teenager" and adolescent.

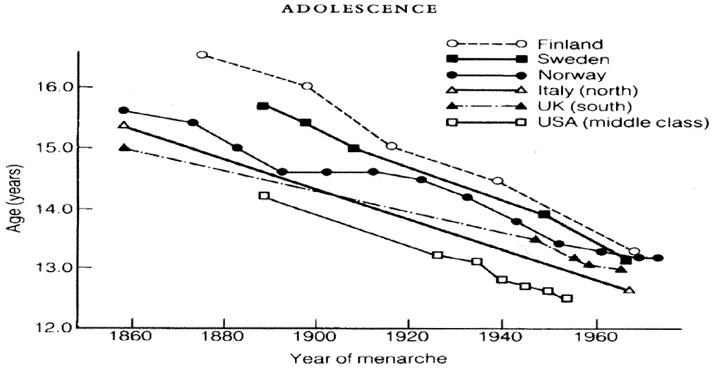

FIGURE 2. Age at menarche, 1860–1970. (Data from Tanner.[9])

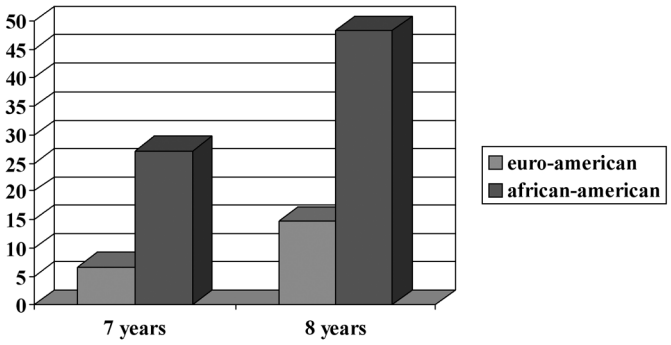

FIGURE 3. Percentage of girls who have reached at least Tanner State 2 of breast and/or pubic hair by ages of 7 and 8.

ADOLESCENCE: AN ANTHROPOLOGICAL PERSPECTIVE

The past 150 years have witnessed a quiet revolution in human development that still sweeps across the globe today: children nearly everywhere are growing faster, reaching reproductive and physical maturity at earlier ages, and achieving larger adult sizes than perhaps ever in human history.

—CAROL M WORTHMAN, PH.D.

In our conceptualization of adolescence as the interval beginning with the physical changes of puberty and ending with the assumption of adult social roles, it becomes clear that this period of adolescent development has undergone a notionally major expansion in recent history. Adolescence is much broader and longer than the teenage years alone. It now stretches, in many cases across more than a decade, with pubertal onset often beginning by 9 to 12 years of age and adult roles delayed until the early twenties.

These changes have been well recognized and discussed by many people in the field, including Carol Worthman, an anthropologist who has studied puberty around the world. Also, Alice Schlegel and Herbert Barry[5] quantified basic aspects of puberty, adolescence, and the transition to adult roles in 187 different societies and summarized their findings in a book that is a fascinating read for anyone interested in adolescent development. Their book, in addition to being rich in anecdotes and cross-cultural observations about adolescence, also contains quantified summaries of key variables using well-defined measures. These data show that the majority of these societies have a developmental period that we could recognize as adolescence—conceptualized as a transition from the status of a child to that of an adult. Moreover, in many societies, the end of childhood was clearly demarcated by some sort of ritual. The onset of adult status in traditional societies was usually defined in

terms of marriage, work roles, hunting, owning property, becoming a parent, or taking on some other specific adult role.

They found that in most traditional societies the interval between puberty and achieving adult status was relatively brief. Marriage among girls occurred within 2 years of the onset of puberty in 63% of the 186 societies studied. Among boys, where the ability to take a wife could require a specific level of achievement, such as making a first kill on a hunt, or developing a specific set of skills that increased the economic ability to provide for a family, the interval was significantly longer than for females, but still 64% of the males were married within 4 years of puberty. Thus, the adolescent interval between puberty and adult roles typically occupied a 2- to 4-year period in the majority of these societies.

Puberty versus Adult Social Roles in Contemporary Society

The situation in many contemporary societies is in sharp contrast to the data from traditional societies. While puberty is occurring earlier in many industrial societies, marriage and other adult roles are often delayed. In the U.S., the average age of menarche is now at age 12, while the average age of first marriage is 26—a 14-year transition, as opposed to the 2–4-year interval typical in females in the majority of traditional societies. This temporal elongation reflects not only the increasingly earlier development of puberty over the past 100 years, but also the increasingly longer time to marriage. In 1970 in the U.S. the timing of first marriage was age 21 for women and 23 for men; by the 2000 census, this had changed to ages 26 and 27, respectively.

A similar set of changes have occurred in other contemporary societies. In Japan, for example, the average age of menarche has decreased 4 years over the past century (from an average of 16.5 years in 1875 to an average of 12.2 years in 1975), while the average age at first marriage in Japan has increased to 26 years for women and 28.4 for men.

This is not simply a matter of changing attitudes about marriage. If one looks at other indices of adult social roles—starting careers, owning a home, choosing to become parents—it is apparent that these are also occurring more than a decade after puberty in most cases.

So, for most of human human history, adolescence has occupied a relatively brief time in individual and societal human development, lasting typically 2 to 4 years. Currently, however, it has stretched out into period that lasts 8 to 15 (or more) years in many contemporary societies.

This expansion of the period of adolescence has some advantages: Several types of opportunities are created by this prolonged interval—it permits adolescents more time to learn complex skills and to develop a variety of capabilities prior to taking on the constraints and demands of adult responsibilities. More time is available for formal education, for learning sports and arts, and for exploring a range of possible career choices; and it allows an individual more opportunities to explore different friendships, peer groups, and romantic relationships that may or may not lead to marriage. But stretching out these developmental processes does not come without costs and vulnerabilities, including the broad range of behavioral and emotional health risks that have an impact on so many youth.

HISTORICAL CHANGES IN ADOLESCENCE: IMPLICATIONS REGARDING THE BRAIN

These historical changes and the relative temporal expansion of the period of adolescence has important implications for understanding the component processes of adolescent brain development. The earlier onset of puberty results in a relatively earlier activation of *some* neurobehavioral changes, raaising several provocative questions about the interrelationship with components of adolescent development that occur on a different time scale—particularly those aspects of adolescent brain development that continue to undergo important maturational changes long after puberty is over. In other words, it appears that the rapid prolongation of adolescence as a developmental period has also contributed to alterations in the timing and interrelationship of components of adolescent brain maturation.

The key principle here can be illustrated by a couple of clinical cases. Consider the cognitive development of an 8-year-old girl with a simple case of precocious puberty. There is no reason to expect that the early activation of reproductive maturity would create a parallel advance of cognitive development; even if physical development, sexual maturation, and bone age are consistent with those of a 14-year-old girl, she will still still have an 8-year- old's level of experience, reasoning ability, logic, and other mental capabilities. In a similar way, consider the relative cognitive development of two otherwise normal 15-year-old boys, if one has already progressed physically through puberty and looks like a mature young man, while the other is still pre-pubertal with the physical development of a young boy. Is there any basis for assuming the more physically mature 15-year-old would show any specific areas of mental ability superior to the prepubertal boy's? In fact, there is a fairly extensive clinical literature that shows that most patients who are clinically delayed in the onset of puberty—or even among those who fail to go through puberty at all because of an endocrine disorder or physical intervention, as done to the *castrati* to provide high voices for a church choir—most aspects of mental development proceed in a completely normal manner. In other words, most elements of cognitive development show a trajectory that follows age and experience rather than the timing of puberty.

This principle has direct implications regarding the recent historical changes in pubertal timing. While some neurobehavioral changes (such as drives and emotional changes at puberty) are occurring at earlier ages, many other aspects of neurocognition progress slowly, and continue to mature long after puberty is over. Thus, the recent expansion of the adolescent period has also stretched out the interval between the onset of emotional and motivational changes activated by puberty, and the completion of cognitive development—the maturation of self-regulatory capacities and skills that are continuing to develop long after puberty has occurred.

PUBERTY AND BRAIN DEVELOPMENT

Given these changes in the timing of puberty and the expansion of adolescent maturation more broadly, it is important to consider what is known about puberty and brain development. First we know that some brain changes *precede* the pubertal increases in hormones. Pubertal maturation *starts* in the brain, some neural changes

leading directly to the hormonal cascade at the beginning of puberty. I will refer to these as *upstream* changes as they occur prior to pubertal changes in the body.

Second, clearly there are some brain changes that are the *consequence* of pubertal processes. Once these hormone levels increase in the body, there is some feedback to specific brain systems, what I will call *downstream* changes since they occur as a consequence of the physical development and accompanying increase in hormone levels affecting the brain. One recent area of research regarding pubertal hormone effects on the brain has focused on the discovery of a new type of estrogen receptor in several regions of the brain—the beta-estrogen receptor; this will be discussed in much greater detail by Judy Cameron in Part 3 of this book. This system appears to be the mechanism for some of the behavioral or emotional changes resulting from the increased reproductive hormones of puberty, such as changes in serotonergic regulation mediated by beta-estrogen.[6]

Third, some aspects of adolescent brain maturation and cognitive development appear to be independent of pubertal processes and continue long after puberty is over.

The existence of these three different categories of links—upstream changes, downstream changes, and puberty-independent maturational changes—makes it clear that changes in pubertal timing create the *potential for internal dys-synchrony* among the components of adolescent brain maturation.

This also highlights the importance of considering *puberty-specific changes* in neurobehavioral maturation within a broader range of developmental changes across adolescence, which has important conceptual as well as methodological implications. In most studies in adolescents, these domains become confounded in ways that do not allow investigators to disentangle these effects. Many studies do not contain any measures of puberty; and even among those that collect some data about level of reproductive maturity, these measures of pubertal development, age, and social experience can be correlated in ways that make it impossible to examine the effects of age versus [ubertal maturation. There are, however, some interesting and provocative exceptions— studies that have been designed to disentangle puberty-specific changes that point to important issues and questions. Examples of research showing puberty-specific changes in affective domains are discussed next.

PUBERTY-SPECIFIC CHANGES IN AFFECTIVE DOMAINS

A study that has found behavioral changes that are specifically linked to puberty is that of Martin and colleagues,[7] who investigated the development of smoking and other risk-taking behaviors in adolescents. They included a measure of sensation seeking as well as measures of pubertal maturation in a sample with a relatively narrow age band: most subjects were 11 to 13 years old. Interestingly, within this age range, there were no significant correlations between age and sensation seeking—the older kids were no more likely to rate themselves as higher in their desire for thrilling or exciting experiences. However, there was a *significant positive correlation between pubertal maturation and sensation seeking* in both the boys and girls, and this was associated with greater risk taking and smoking. Among individuals of similar age, those who were more advanced in puberty were more likely to seek exciting experiences and to show risk-taking behavior.

TABLE 1. Developmental domains having evidence for puberty-specific maturational changes

- romantic motivation
- sexual interest
- emotional intensity
- changes in sleep/arousal regulation
- appetite
- risk for affective disorders in females
- increase in risk taking, novelty seeking, sensationseeking (reward-seeking)

There are several developmental domains where there is evidence for *puberty-specific* maturational changes (TABLE 1). It is important to emphasize the need for more studies that are designed to examine (and disentangle) age and pubertal effects. However, from the handful of studies that have succeeded in examining some of these issues, some themes are emerging. The existing evidence indicates that there are several domains that seem to link more strongly to puberty than age during adolescent development, and most of these are *affective* measures—related to emotion, motivation, arousal, and appetitive or drive systems. These include pubertal changes in romantic and sexual interests, mood lability, emotional intensity, reward seeking and/or sensation seeking, changes in sleep/arousal regulation, increased appetite, and risk for affective disorders among girls.

Some important caveats should be mentioned here: Remember that there is a wide range of individual differences with respect to these pubertal changes. Many adolescents show very subtle changes in the direction of sensation seeking, and these problems are easily managed without any reckless behavior or emotional problems. On the other hand, taken together, this pattern of findings suggests that the primary puberty-specific changes are related to activation of the strong drives, appetites, emotional intensity, and sensation seeking that occurs at puberty. In addition, this set of adolescent changes is occurring relatively earlier as puberty is occurring relatively earlier. In contrast, most aspects of cognitive development—including reasoning, logic, and capacities for self-regulation of emotions and drives—are still developing slowly, and continue long after puberty is over.

STARTING THE ENGINES WITH AN UNSKILLED DRIVER

This metaphor—of an early activation of strong "turbo-charged" feelings with a relatively unskilled set of "driving skills" or cognitive abilities to modulate strong emotions and motivations—has been used a great deal by our ADAPT Research Network.[8] This metaphor is one way to capture the relatively earlier timing of these "igniting passions" at puberty—passions that refer not only to romantic and sexual interests, but also to the intensification in many kinds of goal-directed behaviors that emerge in adolescence. Early adolescence is a time when many teenagers become passionate about a particular sport, hobby, music, art, or literature. It is also a time of passionate commitments to idealistic causes.

These motivational and emotional changes at puberty represent a relatively understudied aspect of adolescent development. Yet, this is an enormously important dimension of understanding the neurobehavioral underpinnings of vulnerability in adolescence. It is crucial because this early activation of intense motivations and passions, which can be channeled into a wide range of activities and types of pursuits, can be shaped by the particular experiences at this point of life. Moreover, when these passions flare up to intense levels, these young peoplet often have not yet developed the skills that can harness these strong feelings (nor have they yet achieved the neural maturation of underlying control systems).

Being a responsible adult requires developing self-control over behavior and emotions to appropriately inhibit and modify behaviors—despite strong feelings—to avoid terrible consequences. It requires that individuals be capable of initiating and carrying out a specific sequence of steps toward a long-term goal even though it may be difficult (or boring) to persist in these efforts. Adolescents need to learn to navigate complex social situations despite strong competing feelings. Skills in self-regulation of emotion and complex behavior aligned to long-term goals must be developed. These self-regulatory processes are complex and mastering behavioral skills involves neurobehavioral systems served by several parts of the brain. The ability to integrate these multiple components of behavior—cognitive *and* affective—in the service of long-term goals involves neurobehavioral systems that are among the last regions of the brain to fully mature. This point is a central focus of this symposium.

We come back to the question of what happens to cognitive development when puberty occurs earlier. A strong body of work suggests that most measures of cognitive development correlate with age and experience—not sexual maturation. Measures of planning, logic, reasoning ability, inhibitory control, problem solving, and understanding consequences are probably not puberty-linked, but depend on age and experience. And these abilities clearly continue to develop long after puberty is over as many aspects of brain development continue to occur long after puberty is over. Jay Giedd and other presenters in Part 2 describe these issues in much greater detail. Elizabeth Sowell and her colleagues at UCLA also have contributed a great deal of data (and conceptual and methodological advances) in these areas. Taken together, a large body of work has shown that structural maturational changes in the brain are continuing long after the interval of puberty is over.

So we return to the metaphor of turbo-charging the engines of a fully mature "car" beloinging to an unskilled driver, whose navigational skills are not yet fully in place. The pubescent youth has several years with a sexually mature body and brain systems that are activated for sexual and romantic interest and passions, but a relatively immature set of neurobehavioral systems for self-control and affect regulation. This "disconnect" predicts risk for a broad set of behavioral and emotional problems, and not just through recklessness, risk taking, and sensation seeking, but also in just navigating complex social situations and attempting to master strong emotions. The affective disorders of adolescence are as informed by this model as are more impulsive and externalizing disorders. Adolescence proves to be a difficult period to develop positive abilities to use strategies, make plans, set goals, learn the social rules, and navigate ambiguous situations as the cognitive and emotional systems are integrated.

THE DEVELOPMENT OF AFFECT REGULATION

I would like to mention here the links to one line of investigation—the development of affect regulation in adolescence—which has been the focus of investigation in my laboratory and of the ADAPT nterdisciplinary research network. First, it is important to delineate what is meant by the term *affect regulation.* It is not simply the process of experiencing and/or expressing emotions, but rather involves controlling one's feelings—modulating them in *adaptive* ways in order to achieve goals, to act with the norms of social rules and expectations and in ways that *support* rather than interfere with decision-making. Several investigative teams are beginning to address some of these issues of emotion and decision-making, including the role of strong emotions during adolescence. The term "hot cognition" refers to the process of thinking under conditions of high arousal and/or strong emotion, as opposed to "cool cognition," thinking under conditions of low arousal and calm emotions.

Adolescents often appear to be relatively good at making decisions under conditions of low arousal and cool emotions, this same highly intelligent youth, under intense emotional arousal, can have a much more difficult time making a responsible can experience a much more difficult time making a responsible choice. This leads, then, to another set of pragmatic questions: at what age (or based on what maturational criteria) should society *expect* individuals to make reliable independent decisions?—and be held legally responsible for these choices? As will be discussed later, Laurence Steinberg and several of his colleagues have been grappling with legal and scientific aspects to these questions. What if the average 15-year-old is capable, under "cool" conditions, of understanding the consequences of his behavior in a way that is comparable to that of adults, but is more emotionally reactive to irrational influences under conditions of "hot" cognition? How should we interpret data that show that a particular 16-year-old has adult capabilities to use logic and understand the consequences of his behavior, if we observe him, when in a group of friends, making reckless choices that the average 9-year-old would say was a pretty dumb thing to do? The point is that the age at which one has the ability to understand cognitively that a particular course of action is wrong may not be the same age as having reliable self-control over his strong emotions "hijacking" his decision-making.

There is much ambiguity and controversy in state, national, and even international policies about when society should allow individuals to make which type of decisions as adults. Why is that a young person is not able to drive a car until 16, vote until 18, drink alcohol until 21, rent a car from a commercial agency until 25, but, in some states, can stand trial for murder at age 12 or 13? At what age should youth be free to make decisions about their own health risks—such as smoking or having (or refusing) an operation, or having an abortion? At what age should he or she be able to decide to quit school, join the armed services, or get married? At what age should he or she be free to make potentially self-destructive choices such as body piercing, tattoos, acting in pornographic films, or gambling?

Leaving aside the personal and political controversies that such questions often stir up, the compelling issue for this symposium focuses on the potential for *science* to contribute to these important debates. Scientific study can shed light and offer rational approaches to these questions. If science can provide clear evidence for an im-

maturity of neural systems that affect decision making or abilities to regulate affect in adolescence—and if there are objective criteria for assessing the level of maturation that are not simply based on an arbitrary number of birthdays—science can be said to be making very important contributions to the legal, ethical, and moral questions about adolescent responsibility.

SOCIAL CONTEXTS AND ADULT SCAFFOLDING OF ADOLESCENT EXPERIENCE

During this period of gradual and inconsistent emergence of skills and knowledge needed to take on adult roles and decisions—and the still maturing neurobehavioral systems that undergird these skills—there is a need for a social context that can provide the appropriate amount of support to adolescents. It is crucial for adolescents have the appropriate social *scaffolding*—the right balance of monitoring and interest from parents, teachers, coaches and other responsible adults—in which to develop the skills of self-control while still being afforded sufficient support and protection. Ideally this scaffolding should, gradually fade, allowing adolescents to make increasingly independent decisions without placing them in situations that they are not yet ready to handle. Clearly, this is an ideal scenario that far too many adolescents—especially those in high-risk social contexts—never experience. Ann Masten has noted that adult monitoring is all too frequently and too prematurely withdrawn during this vulnerable period, leaving the adolescent to have to navigate situations alone or with peers at a relatively early age. This kind of mismatch between biological maturity, without equivalent cognitive-emotional maturity, in a sometimes dangerous social context and with only minimal adult supervision, plays a part in creating a great deal of vulnerability for youth in our society.

At the conference on which this book is based, we had the opportunity to view excerpts from a recent movie called "Thirteen" that illustrate these issues. This movie was co-written by a 13-year-old (who is also one of the actors in the film) along with the director. It captures, among other things, the intensity and abruptness, of making the transition from a period of playing with Barbie dolls and stuffed animals to an urban world of a teenager plunging into a confrontation with drugs, sex, and the exciting, but highly destructive allure of reckless adventure. It is a distressing clip— and a disturbing movie— which is worth seeing by anyone who wants to witness an example of the real-world difficulties facing so many early adolescents in contemporary society—a movie that raises many provocative questions about the dangers of this period of suddenly igniting passions that we have been talking about.

THE ADOLESCENT BRAIN: A NATURAL TINDERBOX

The natural adolescent inclinations toward novelty, arousal, and excitement that emerge in association with puberty create an emotional tinderbox in which passions—both negative and positive—are ignited. This creates both a great deal of vulnerability among the young as well as a great opportunity to harness these emotions in the service of positive goals. And young people are often eager to face a great deal of risk to achieve the high-intensity feelings that can be so appealing in adolescence.

Puberty itself seems to increase the appetite for a specific type of emotional experience: surges of arousal and cravings for exhilaration. This type of appetite even seems to feed on itself, as it moves behavior toward seeking yet more and more arousal and stimulation.

Fortunately, these emotional and motivational changes at puberty—these igniting passions—do not lead only to to bad outcomes: Sex, drugs, loud music, and reckless behavior are not the *only* ways to activate the kinds of high-intensity feelings that are so appealing to adolescents. The efforts necessary to achive a goal or to face a challenge can also become sources of positive, high-intensity feelings. And struggling to overcome adversity or to master a skill can also lead to inspired actions and the high-intensity feeling that can come from achieving a much-desired goal.

So these igniting passions can be aligned in *healthy* ways—in the service of higher goals. Feelings of passion are rooted in the same deep brain systems as biologic drives and the primitive elements of emotion. Yet passion intertwines with the highest levels of human endeavor: passion for ideas and ideals, passion for beauty, passion to create music or art. And the passion to succeed in a sport, business, or politics, and passion toward a person, activity, object, or pursuit can also inspire transcendent feelings.

One of the most important questions facing parents, teachers, clinicians treating adolescents, political leaders, and those of conducting science that can inform social policyis: *how* are adolescent passions being captured in modern society? How are these new intense motivational systems in the adolescent brain being shaped in ways that are healthy or unhealthy? For example, the emergence of religious zeal in adolescents can fuel positive humanistic efforts to feed the poor and care for the sick, yet, it can also lead to dogmatic attitudes, intolerance, or rash polical action. Igniting passions can lead to idealistic efforts by youth who strive to make the world a better place or these passions can be captured by a negatively charismatic figure like Adolf Hitler or Osama bin Laden, who instead inspire destructive, despairing and evil deeds.

IGNITING PASSIONS IN ADOLESCENCE: A PERIOD OF SCIENTIFIC OPPORTUNITIES

These questions about emotional and motivational changes in adolescence have profound implications for the future of youth in our society, and represent part of the reason greater scientific detail is needed to understand these maturational processes and to provide further insights regarding the types of experiences needed to shape these igniting passions in ways that serve larger humanistic goals.

This igniting of passions—this activation of overwhelming levels of emotion that can transiently block the capacity to think, reason, and proceed logically according to consequences—has an underlying neural circuitry. There are several important scientific questions about the neurobehavioral changes underpinning this temporary loss of the ability to plan and to reason. Adolescence is a developmental period when new links are established in the brain that create connections between affective and cognitive processes. For example, adolescence is a time for developing a new sense of self and identity along with the cognitive ability to imagine oneself in the future in ways that can create positive emotions (picturing oneself as highly successful) as well as linked to negative affective appraisals (imaging the consequences of failure

or humiliation). This cross-temporal processing of thoughts and images can create strong feelings in adolescence that are capable of altering motivation. Most importantly, many of these more complex cognitive-emotional experiences are happening for the first time in adolescence. These new experiences are creating new patterns of neural connections. Understanding more of the details of how and when these are occurring can create opportunities for investigators to identify ways to intervene in high-risk youth at a time when some of these systems are more plastic to change. Scientific knowledge can thus be brought to bear in preventing some of the destructive negative spirals that can begin in adolescence.

Adolescence thus offers a period of scientific opportunity: it's a chance to identify key developmental processes in puberty and adolescence that are amenable to intervention. We need to learn what *kinds* of interventions will work with *which* problems and what is the best *time* to apply them. Increasingly, the advances in basic neuroscience, genetics, developmental psychology, and the use of animal models will be combined with clinical and social policy work to implement change and point to the key questions that should be priorities for the more basic investigators. My hope for this symposium is that it will spark a series of dialogues across these disciplines to integrate current knowledge, refine our conceptual models, and to focus the directions of future work that will—in the long run—have a large positive impact on the health and well being of the youth in our society.

We search, on our journeys,
for a self to be, for other selves to love,
and for work to do…
We find by losing. We hold on by letting go.
—FREDERICK BUECHNER

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A Period of Vulnerabilities and Opportunities. Keynote Address. Ronald e. dahl. Psychiatry and Pediatrics, University of Pittsburgh Medical CenterÂ Research now suggests that the human brain is still maturing during the adolescent years, with changes continuing into the early 20s. The immature brain of the teenage years may not only explain why adolescents are prone to make poor decisions, but it may also place teenagers at an elevated risk to the harmful effects of drugs. Work In Progress Advanced technologies in brain imaging have provided windows to the developing brain. Young adolescents need opportunities to form relationships with adults who understand them and who are willing to support their development. Educational as well as advisory programs and practices can promote an atmosphere of friendliness, concern, and group cohesiveness (Kellough & Kellough, 2008). Moreover, teachers can acknowledge the importance of friendships and help students to understand that shifting allegiances are normal (Scales, 2003).Â Adolescent brain development: A period of vulnerabilities and opportunities. Keynote address. In R. E. Dahl & L. P. Spear (Eds.), Annals of The New York Academy of Sciences: Vol. 1021. Adolescent brain development: Period of vulnerabilities and opportunities (pp. 1â€“22).