Science on Adolescent Development

"Compared to adults, adolescents are more susceptible to peer influence, less oriented to the future, more sensitive to short-term rewards, and more impulsive. This research on adolescent brain, cognitive, and psychosocial development supports the view that adolescents are fundamentally different from adults in ways that warrant their differential treatment in the justice system."

- ***Adolescent Development and Juvenile Justice***
  Laurence Steinberg, 2009

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REVIEWS IN ADVANCE

Adolescent Development and Juvenile Justice

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Abstract

Although justice system policy and practice cannot, and should not, be dictated solely by studies of adolescent development, the ways in which we respond to juvenile offending should be informed by the lessons of developmental science. This review begins with a brief overview of the history, rationale, and workings of the American juvenile justice system. Following this, I summarize findings from studies of brain, cognitive, and psychosocial development in adolescence that have implications for the treatment of juveniles in the justice system. The utility of developmental science in this context is illustrated by the application of these research findings to three fundamental issues in contemporary justice policy: the criminal culpability of adolescents, adolescents' competence to stand trial, and the impact of punitive sanctions on adolescents' development and behavior. Taken together, the lessons of developmental science offer strong support for the maintenance of a separate juvenile justice system in which adolescents are judged, tried, and sanctioned in developmentally appropriate ways.

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INTRODUCTION

Few issues challenge a society's ideas about both the nature of human development and the nature of justice as much as serious juvenile crime. Because we neither expect children to be criminals nor expect crimes to be committed by children, the unexpected intersection between childhood and criminality creates a dilemma that most people find difficult to resolve. Indeed, the only ways out of this problem are either to redefine the offense as something less serious than a crime or to redefine the offender as someone who is not really a child (Zimring 1998).

For most of the twentieth century, American society has most often chosen the first approach—redefining the offense—and has treated most juvenile infractions as matters to be adjudicated as delinquent acts within a separate juvenile justice system designed, at least in theory, to recognize the special needs and immature status of young people and to therefore emphasize rehabilitation over punishment. Indeed, for much of the past century, states believed that the juvenile justice system was a vehicle to protect the public by providing a system that responds to children who are maturing into adulthood. States recognized that conduct alone—that is, the alleged criminal act—should not be dispositive in deciding when to invoke the heavy hand of the adult criminal justice system. They recognized that by providing for accountability, treatment, and supervision in the juvenile justice system—and in the community whenever possible—they promoted short-term and long-term public safety.

During the last two decades of the twentieth century, there was a dramatic shift in the way juvenile crime was viewed by policy makers and the public. Rather than choosing to define offenses committed by youth as delinquent, society increasingly opted to deal with young offenders more punitively in the juvenile justice system or to redefine them as adults and try them in adult criminal court. This trend was reflected in the growing number of juvenile offenses adjudicated in adult criminal court, where adolescents are exposed to a far more adversarial proceeding than in juvenile court; in the increasingly punitive response of the criminal justice system to juvenile offenders who are found guilty; and in what some observers have referred to as the "criminalization" of the juvenile justice system itself through increased use of punishment, rather than rehabilitation, as a legitimate juvenile justice goal (Feld 1993).

This transformation of juvenile justice policy and practice raises difficult, but important, questions for psychologists interested in the development and well-being of young people.

These questions are variations of the more general question of whether adolescents are fundamentally different from adults in ways that warrant the differential treatment of juveniles who break the law. In particular:

- Do adolescents have the psychological capabilities necessary to function as competent defendants in adult court?
- Should juveniles accused of crimes be held to the same standards of blameworthiness as adults and punished in the same ways as adult criminals who have committed similar crimes?
- How does exposing juveniles to especially punitive sanctions affect their behavior, development, and mental health?

These questions provide this review's focus. More broadly, the purpose of this review is to integrate developmental psychological considerations into moral, legal, political, and practical analyses of juvenile crime. Because addressing this issue necessitates at least a rudimentary understanding of the rationale and workings of the juvenile justice system, I begin not with a discussion of the science of adolescent development, but rather with a short history of juvenile justice in America and a brief overview of the process through which individuals are adjudicated within the system.

Following this brief introduction to American juvenile justice, I then summarize findings from recent studies of adolescent development that bear on whether adolescents differ from adults in ways that have implications for justice system policy and practice. Because not all aspects of adolescent development are pertinent to how young people are, or should be, treated in the justice system, I limit my discussion to studies that are especially relevant to these issues. Readers interested in a broader and more comprehensive treatment of adolescent development are encouraged to consult several recent reviews of this literature (Collins & Steinberg 2006, Smetana et al. 2006) as well as a recently updated handbook on adolescent psychology (Lerner & Steinberg 2009). I then look specifically at what we know about adolescents' competence to stand trial, criminal culpability, and response to various types of sanctions and interventions.

Competence to stand trial: the ability of a defendant to understand the court proceeding, reason with relevant facts, and assist counsel

Criminal culpability: the extent to which an individual is judged to be responsible for a crime

JUVENILE JUSTICE IN AMERICA: AN OVERVIEW

The Origins of the Juvenile Justice System

Economic recessions in the early nineteenth century pushed children out of work in America's new factory system during the industrial revolution. Concerns about poor children on the street led to the creation of institutional care for children. In New York City, the Society for Prevention of Pauperism in 1824 became the Society for the Reformation of Juvenile Delinquents, and in 1825 opened the nation's first House of Refuge. Boston followed a year later and Philadelphia in 1828. These Houses of Refuge were designed to maintain class status and prevent unrest (Krisberg & Austin 1993, Platt 1977).

In 1899, Jane Addams and her Hull House colleagues established what is generally accepted as the nation's first juvenile court. Juvenile court judges, in the early part of the twentieth century, were authorized to investigate the character and social background of both predelinquent and delinquent children. They examined personal motivation as well as criminal intent, seeking to identify the moral reputation of problematic children (Platt 1977). Ben Lindsey, of Denver, was the juvenile court judge whose practice most closely matched the rhetoric of the emerging juvenile court:

> We should make it our business to study and know each particular case, because it will generally demand treatment in some little respect different from any other case.... (a) Is the child simply mischievous or criminal in its tendencies? (b) Is the case simply an exceptional or isolated instance in which a really good boy or girl has gone wrong for the first time because too weak to resist a strong temptation? (c) Is the child a victim of incompetent

Transfer: one mechanism through which juveniles' cases are referred to criminal (adult) court

Disposition: in the juvenile justice system, the outcome of an adjudication; comparable to a sentence in criminal court

> parents? Does the home or parent need correction or assistance? (d) What of environment and association, which, of course, may embrace substantively all of the points of study? How can the environment be improved? Certainly by keeping the child out of the saloon and away from evil examples. (e) Is the child afflicted with what we call "the moving about fever" – that is, is he given to playing "hookey" from school, or "bumming" and running away, showing an entire lack of ambition or desire to work and settle down to regular habits? [Ben B. Lindsey, "The Boy and the Court," *Charities* 13 (January 1905):352; cited in Platt (1977)]

Julian Mack, Chicago's second juvenile court judge, similarly described the ideal juvenile court proceeding:

> The problem for determination by the judge is not Has this boy or girl committed a specific wrong but What is he, how has he become what he is, and what had best be done in his interest and in the interest of the state to save him from a downward career. It is apparent at once that the ordinary legal evidence in a criminal court is not the sort of evidence to be heard in such a proceeding. (Mack 1909)

It is beyond the scope of this article to discuss the likely causes of the transformation of the juvenile justice system away from the rehabilitative ideal espoused by its founders and toward the more punitive regime that exists today (but see Scott & Steinberg 2008 for a discussion). However, it is worth noting that the early rhetoric on the rationale and purpose of the juvenile court is significant in two ways that bear on contemporary debates about justice system policy and practice. First, it is clear that the founders of the juvenile justice system began from the premise that adolescents are developmentally different from adults in ways that should affect our interpretation and assessment of their criminal acts. The questions raised by Judges Lindsey and Mack are relevant to the most vexing challenges that practitioners face today in determining (*a*) whether an adolescent's antisocial behavior is due to transient immaturity or contextual disadvantage, as opposed to deep-seated criminal character and (*b*) how best to construct a response to a juvenile's delinquent or criminal acts that will decrease the likelihood of recidivism. The difference between now and then, however, is that at the time of the court's founding, there was no science available to inform consideration of either issue. Owing to the dramatic increase in empirical research on normative and nonnormative adolescent development that began in the late 1970s, there has been a remarkable expansion of the scientific knowledge relevant to each of these matters.

Critical Decision Points Along the Juvenile Justice Pipeline

Juvenile justice is regulated mainly by state law, which makes it difficult to generalize about the system in ways that apply universally. Despite whatever differences exist across jurisdictions in policies and practices, however, the points of decision are essentially similar: referral, intake, detention, transfer, adjudication, disposition, and release (see Steinberg & Schwartz 2000).

Referral. Entrance into the pipeline begins with a referral to the juvenile justice system or a police arrest. Depending upon the state, a child may be too young or too old for the juvenile justice system. Children who are too young are most often diverted from the system or sent to the branch of juvenile court that has jurisdiction over neglected and abused children. Children who are too old are tried as adults. A juvenile may also be charged with an offense that results automatically in adult prosecution. If the juvenile is charged as an adult, most states allow for judges, after a hearing, to decide that the case should be transferred to juvenile court if the public interest requires it, or if the juvenile can prove that he or she is amenable to treatment in the juvenile justice system.

Intake. If the child enters the juvenile justice system after being arrested, referred by a private petitioner (such as a school or next-door neighbor), or transferred from criminal court, there will be an intake decision. Should the case proceed, or should the juvenile be diverted? If the latter, should it be an informal diversion, without further involvement by the juvenile court, or should the child be sent to a program, such as a community panel or teen court (and returned to juvenile court if he or she fails to obey a community-ordered disposition)? Some cases are diverted to other systems, such as the mental health system. Some cases are dropped entirely because intake officers decide that this particular combination of youth and offense does not belong in the juvenile justice system. Many factors thus enter into the decision to divert a case: The youth's age, prior history, the seriousness of the offense, and the youth's explanation or attitude will affect the intake decision.

Detention. If the intake officer decides that the case should proceed to a hearing, the officer must decide whether the child should be sent home (with or without supervision) or should be detained, either in a maximum-security detention center or in a detention alternative. Juveniles and their parents will need to explain to an intake officer how pretrial supervision will occur, and they will have to convince the officer that the juvenile will appear for trial. If the child is detained, there will be a court appearance within 24–72 hours. Most states call this first court appearance a detention hearing. Here a judge or referee will decide whether to continue the detention status. This is usually the first time that the child meets his or her attorney. Here the child must be able to discuss with counsel the circumstances of the arrest and out-of-court issues related to the detention decision (such as school attendance or the presence of an interested adult in the juvenile's life).

Transfer. Most persons under the age of 18 who are tried as adults are done so because of statutory exclusion of their case from the juvenile justice system. State law may exclude them because of their age—in New York, for example, a 16-year-old will be tried as an adult for any offense. Every state excludes some offenses from juvenile court jurisdiction if a child is of a certain age (for example, a state can decide that 15-year-olds who are charged with armed robbery will have their cases begin in adult criminal court). Some states permit prosecutors to file the juvenile's case directly in the adult system, where the juvenile may or may not have an opportunity to have the case transferred to juvenile court. Every state also allows judges to transfer children of a certain age—usually 14, but in some instances, even younger—to criminal court if they are charged with an offense as serious as a felony. States usually must prove that the juvenile is "not amenable to treatment" in the juvenile justice system. At transfer hearings, it is important that the juvenile is able, for example, to discuss with counsel his or her recent placement history and its reason for failure. He or she should be able to understand options, such as proposed placements, counseling programs, or plea agreements.

Adjudication. If the child continues to be detained within the juvenile justice system, an adjudicatory hearing (comparable to the trial in criminal court) must be held within 10–30 days. (Although this is the general rule, in some states juveniles charged with high-profile crimes such as murder will have a longer time to wait until their trials.) Demands on juveniles at adjudicatory hearings are many. They will include the need to understand the nature of the charges against them and to consult with counsel. They will have to weigh the costs and benefits of entering an admission (guilty plea). They should be able to help counsel identify potential witnesses, know whether an alibi or other defenses are available, and consult with counsel during cross-examination of state witnesses.

Disposition. If the juvenile admits to the offense, or if the juvenile court finds by proof beyond a reasonable doubt that the child has committed the offense, the court will proceed to disposition (sentence). Juveniles are expected to assist counsel in presenting disposition options to the juvenile court. Assistance might include suggesting dispositions or helping the attorney and experts develop client-specific dispositions. Juvenile dispositions historically have been aimed at providing treatment, rehabilitation, or supervision in a way that best serves the needs of the juvenile, although in recent years some legislatures also have included incapacitation for public safety as a valid rationale. Under any of the models, the juvenile court will have a range of discretion. In some states, the juvenile court has wide latitude, from ordering that a child return home under supervision (probation) to placing a child in maximum-security institutions, known as training schools, reform schools, or youth development centers. In other states, which use a "youth authority" model, the court will either order probation or, if placement is warranted, transfer custody of the child to the youth authority, which will then determine the appropriate level of care.

Release. Most juvenile court dispositions are for indeterminate periods of time. However, dispositions cannot be for a longer period than an adult would serve for a similar crime in the criminal justice system. The court will usually review the juvenile's case every six to nine months. Sometimes the reviews are formal hearings, whereas in other instances they are informal reviews of reports provided by probation officers or institutional staff. Many juveniles in placement, particularly those with mental health needs or who have been placed in inappropriate placements, end up being returned to juvenile court for a new disposition. Most often, those juveniles are placed in detention pending a new placement plan. When juveniles are released from institutions, they are placed on aftercare probation, which is analogous to parole. A juvenile who is on probation or on aftercare probation status can have that status revoked, or "violated," for new offenses or for violating the terms of probation, such as associating with gang members, truancy, or missing curfew. A violation of probation may lead to rearrest, detention, and another hearing, the outcome of which may be a new disposition.

The Relevance of Developmental Science to Decision Making in the Justice System

Although there are few decision points in the pipeline where the developmental status of the juvenile is taken into account explicitly, at each decision juncture, information about the juvenile's stage of development should play an important role in the outcome of the decision. A juvenile's developmental status is relevant with respect to the adjudication process because a just and fair hearing requires the competent participation of the individual in his or her defense. As noted earlier, at both the adjudication and transfer hearings, certain competencies are expected to be in place, including those that potentially affect the juvenile's ability to understand the charges, assist counsel, and enter pleas (Scott & Grisso 2005). To the extent that these competencies are based on capabilities that develop over the course of childhood and adolescence, an accurate understanding of how and along what timetable these capabilities develop is crucial to deciding whether an individual possesses the skills necessary to participate in the process.

Under the law, characteristics of the offender and the circumstances of the offense can mitigate criminal responsibility and lessen the punishment that is ordered by the court. A crime that is committed impulsively is punished less severely than one that is premeditated, as is a crime that is committed under coercive pressure from others. Familiarity with the expected developmental timetables of phenomena such as self-control, foresight, and susceptibility to peer pressure is therefore important for making determinations of culpability. In theory at least, an offender who, by virtue of developmental immaturity, is impulsive, shortsighted, and easily influenced by peers should be punished less harshly than one who is better able to control himself, anticipate the future consequences of his behavior, and resist the antisocial urgings of his friends (Steinberg & Scott 2003).

Finally, decision makers in the system often must assess the youngster's potential for change and risk for future offending when making transfer or disposition decisions (Mulvey & Leistico 2008). Such determinations of developmental plasticity are especially important at transfer hearings, because a youngster who is or seems hardened and unlikely to profit from rehabilitation is more likely to be charged as an adult than is one who is or is seen as malleable and amenable to intervention. Similarly, a juvenile who is deemed to be at high risk of recidivism, either because of a long prior record of offending or other characteristics associated with continued and/or dangerous criminal behavior (e.g., failure to respond to prior attempts at rehabilitation, a history of uncontrollable violence, or likelihood of inadequate adult supervision in the community) will be more likely to be sent to institutional placement.

In order to make well-informed decisions about the treatment of juveniles who have entered the juvenile justice pipeline, therefore, policy makers, practitioners, and mental health professionals need to be familiar with the developmental changes that occur during childhood and adolescence in the capabilities and characteristics that are relevant to competence, culpability, and likely response to treatment. Legislators need this information in order to create age-related laws and statutes that are developmentally appropriate and scientifically reasonable; if, for example, we know that the ability to understand charges or enter pleas does not generally develop until a certain age, it makes little sense to draw age boundaries that would subject developmentally incompetent individuals to court proceedings that necessitate their participation in order to satisfy ordinary due process requirements. Judges need this information in order to make wise and fair decisions in the courtroom; if we know that the capacity to regulate one's own behavior is unlikely to be present before a certain age, it is important that this information be taken into account at the time of sentencing or disposition. Mental health professionals need this information in order to perform accurate assessments and make appropriate treatment recommendations; individuals at different stages of development may need very different sorts of interventions. And attorneys need this information in order to practice law more effectively; prosecutors may consider a juvenile's developmental status in deciding when it is appropriate to charge an individual as an adult, and defense attorneys need to know how best to interact with clients who may not fully understand their situation. Understanding the nature of psychological development during adolescence, therefore, will likely improve policymaking, judicial decision making, forensic evaluation, and legal practice.

BRAIN, COGNITIVE, AND PSYCHOSOCIAL DEVELOPMENT IN ADOLESCENCE

When lawmakers focus on juvenile justice policy, the distinction between adolescence and adulthood, rather than that between childhood and adolescence, is of primary interest. However, most studies of adolescent development have compared adolescents with children, and only in recent years has scientific interest focused intensely on the psychological transition between adolescence and adulthood, largely in response to new research showing continued brain maturation through the end of the adolescent period. This work has provided support for the uniqueness of adolescence as a stage of life that is also distinct from adulthood with respect to several aspects of brain and psychosocial development.

Adolescent Brain Development

Although most of the developmental research on cognitive and psychosocial functioning during adolescence involves psychological studies, recent work in developmental neuroscience is beginning to shed light on the neural underpinnings of psychological development across adolescence and adulthood. In the past several years, a new perspective on risk taking

Socioemotional system: the brain system governing the processing of social and emotional information and the experience of reward and punishment

Cognitive control system: the brain system governing executive function, including deliberative thinking, impulse control, foresight, and the evaluation of risk and reward

(including antisocial risk taking) during adolescence has emerged, one that is informed by advances in developmental neuroscience (Casey et al. 2008, Steinberg 2008). According to this view, risky behavior in adolescence is the product of the interaction between changes in two distinct neurobiological systems: a socioemotional system, which is localized in limbic and paralimbic areas of the brain, including the amygdala, ventral striatum, orbitofrontal cortex, medial prefrontal cortex, and superior temporal sulcus; and a cognitive control system, which is mainly composed of the lateral prefrontal and parietal cortices and those parts of the anterior cingulate cortex to which they are interconnected (Steinberg 2007).

According to this dual-systems model, adolescent risk taking is hypothesized to be stimulated by a rapid and dramatic increase in dopaminergic activity within the socioemotional system around the time of puberty, which is presumed to lead to increases in reward seeking. However, this increase in reward seeking precedes the structural maturation of the cognitive control system and its connections to areas of the socioemotional system, a maturational process that is gradual, unfolds over the course of adolescence, and permits more advanced self-regulation and impulse control. The temporal gap between the arousal of the socioemotional system, which is an early adolescent development, and the full maturation of the cognitive control system, which occurs later, creates a period of heightened vulnerability to risk taking during middle adolescence (Steinberg 2008). As one writer has characterized it, the process may be akin to "starting the engines without a skilled driver behind the wheel" (Dahl 2001).

Neurobiological evidence in support of this dual-systems model is rapidly accumulating. A growing literature, derived primarily from rodent studies but with implications for human development, indicates that the remodeling of the dopaminergic system within the socioemotional network involves an initial postnatal rise and then, starting in preadolescence, a subsequent reduction of dopamine receptor density in the striatum and prefrontal cortex; this pattern is more pronounced among males than females (Sisk & Foster 2004, Sisk & Zehr 2005, Teicher et al. 1995). As a result of this remodeling, dopaminergic activity in the prefrontal cortex increases significantly in early adolescence and is higher during this period than before or after. Because dopamine plays a critical role in the brain's reward circuitry, the increase, reduction, and redistribution of dopamine receptor concentration around puberty, especially in projections from the limbic system to the prefrontal area, is likely to increase reward-seeking behavior and, accordingly, sensation seeking.

There is equally compelling neurobiological evidence for changes in brain structure and function during adolescence and early adulthood that facilitate improvements in self-regulation that permit individuals to modulate their inclinations to seek rewards, although this development is presumed to unfold along a different timetable and to be independent of puberty (see Paus 2005 for a summary). Because of synaptic pruning and the continued myelination of prefrontal brain regions, resulting in improved connectivity among cortical areas and between cortical and subcortical areas, there are improvements over the course of adolescence in many aspects of executive function, such as response inhibition, planning, weighing risks and rewards, and the simultaneous consideration of multiple sources of information. There is also improved coordination of affect and cognition, reflected in improved emotion regulation, which is facilitated by the increased connectivity between regions associated with the socioemotional and cognitive control systems.

The development of the cognitive control system, which is manifested chiefly in improved connectivity across brain regions, must be distinguished from the well-publicized maturation of the frontal lobes because of synaptic pruning. Although both processes result in improved thinking abilities, they occur at different times in adolescence and have different implications for cognitive development. Whereas increases in connectivity take place throughout adolescence and well into adulthood, the decline in gray matter density that reflects synaptic pruning takes place in preadolescence and early adolescence and is more or less complete by age 16. Consequently, performance on tasks that activate the frontal lobes continues to improve through middle adolescence but not beyond age 16 on tasks of moderate difficulty (Conklin et al. 2007, Crone & van der Molen 2004, Hooper et al. 2004, Luna et al. 2001). In contrast, adult-like performance on more demanding cognitive tasks, especially those that require coordination between and among multiple cortical and subcortical brain regions, is not attained until later in development.

The upshot of this developmental neuroscience is that changes in the socioemotional system at puberty may promote reckless, sensation-seeking behavior in early and middle adolescence, while the regions of the prefrontal cortex that govern cognitive control continue to mature over the course of adolescence and into young adulthood. This temporal gap between the increase in sensation seeking around puberty and the later development of mature self-regulatory competence may combine to make adolescence a time of inherently immature judgment. Thus, despite the fact that in many ways adolescents may appear to be as intelligent as adults (at least as indexed by performance on tests of information processing and logical reasoning), their ability to regulate their behavior in accord with these advanced intellectual abilities is more limited. As the next section makes clear, research on adolescent cognitive and psychosocial development is consistent with this neurobiological profile.

Adolescent Cognitive Development

The application of information about normative adolescent development to policy and practice in the justice system necessitates differentiating between cognitive and psychosocial development, which appear to follow different developmental trajectories (Steinberg 2008). Briefly, on relatively less-demanding tasks that are mainly or exclusively cognitive in nature, and where improvement in adolescence is likely due to synaptic pruning of the frontal lobes, adolescents evince adult levels of competence by age 16. In contrast, on more challenging tasks that involve the coordination of affect and cognition, and on many measures of psychosocial maturity, performance continues to improve well into young adulthood, most likely because this improvement is mediated by improved connectivity across brain regions, a relatively later development. As I discuss below, this temporal disjunction has created a great deal of confusion with regard to where we should draw the legal boundary between adolescence and adulthood, because different developmental literatures suggest different chronological ages.

The most important cognitive capacities involved in decision making are understanding (i.e., the ability to comprehend information relevant to the decision) and reasoning (i.e., the ability to use this information logically to make a choice). These capacities increase through childhood into adolescence. Between late childhood and middle adolescence (roughly between the ages of 11 and 16), individuals show marked improvements in reasoning (especially deductive reasoning) and in both the efficiency and capacity of information processing (Hale 1990, Kail 1997, Keating 2004, Overton 1990). Research has demonstrated conclusively that, as a result of gains in these areas, individuals become more capable of abstract, multidimensional, deliberative, and hypothetical thinking as they develop from late childhood into middle adolescence (Kuhn 2009). These abilities reach an asymptote sometime around 16, and by this age, teens' capacities for understanding and reasoning in making decisions, at least in controlled experiments, roughly approximate those of adults. This comparability between middle adolescents and adults is not limited to basic cognitive abilities such as memory or verbal fluency or to performance on tasks of logical reasoning. Studies of capacity to grant informed consent to receive medical treatment or participate as a research subject, for example, show little improvement beyond age 16 (Belter & Grisso 1984, Grisso & Vierling 1978, Gustafson & McNamara 1987, Weithorn & Campbell 1982).

The notion that adolescents and adults demonstrate comparable capacities for understanding and reasoning should not be taken to mean that they also demonstrate comparable levels of maturity of judgment, however. As my colleagues and I have argued elsewhere, maturity of judgment is affected both by cognitive capabilities as well as psychosocial ones, and although the former show adult levels of maturity by 16, the latter do not (Steinberg et al. 2008b). As a result, adolescents may be less able to deploy their cognitive capacities as effectively as adults in exercising judgment in their everyday lives when decisions are influenced by emotional and social variables. The development of these psychosocial factors is described in the next section.

Adolescent Psychosocial Development

New perspectives on adolescent "cognition-in-context" emphasize that adolescent thinking in everyday settings is a function of social and emotional, as well as cognitive, processes, and that a full account of youthful judgment must examine the interaction of all of these influences (Scott et al. 1995, Steinberg & Cauffman 1996). Even when adolescent cognitive capacities approximate those of adults, youthful decision making may still differ from that of adults due to psychosocial immaturity. Indeed, research indicates that psychosocial maturation proceeds more slowly than cognitive development, and that age differences in judgment may reflect social and emotional differences between adolescents and adults that continue well beyond mid-adolescence. Of particular relevance to the present discussion are age differences in susceptibility to peer influence, future orientation, reward sensitivity, and the capacity for self-regulation. Available research indicates that adolescents and adults differ significantly with respect to each of these attributes.

Peer influence. Substantial research evidence supports the conventional wisdom that teens are more oriented toward peers and responsive to peer influence than are adults (Steinberg & Monahan 2007). Resistance to peer influence increases between adolescence and adulthood as individuals begin to form an independent sense of self and develop greater capacity for autonomous decision making. Studies of age differences and age changes in resistance to peer influence suggest somewhat different patterns vis-à-vis antisocial versus neutral or prosocial peer pressure prior to middle adolescence (with resistance to antisocial influence decreasing during this time, especially among boys, but resistance to other forms of peer influence increasing), but similar patterns after age 14 (with resistance to all forms of peer influence increasing). Because the main justice policy and practice questions concern differences between adolescents and adults, especially during the latter part of the adolescent period, it is this increase in resistance to peer influence from age 14 on that is of particular interest.

Recent studies of the neural underpinnings of resistance to peer influence in adolescence indicate that improvements in this capacity may be linked to the development of greater connectivity between cortical and subcortical regions, which likely facilitates the better coordination of affect and cognition (Grosbras et al. 2007, Paus et al. 2008), although it should be noted that this conclusion is based on studies of individual differences in brain morphology and function among same-aged adolescents who differ in their self-reported resistance to peer pressure and not to cross-sectional or longitudinal studies that link age differences in resistance to peer influence to age differences in brain structure or function. Nevertheless, it is reasonable to speculate that the social and arousal processes that may undermine logical decision making during adolescence, when connectivity is still maturing, do not have the same impact during adulthood. One recent behavioral study found, for instance, that adolescents, college undergraduates, and adults performed similarly on a risk-taking task when performing the task alone, but that the presence of same-aged friends doubled risk taking among adolescents and increased it 50% among the undergraduates, but had no impact on the adults (Gardner & Steinberg 2005).

Peer influence affects adolescent judgment both directly and indirectly. In some contexts, adolescents might make choices in response to direct peer pressure, as when they are coerced to take risks that they might otherwise avoid. More indirectly, adolescents' desire for peer approval and consequent fear of rejection affects their choices even without direct coercion. The increased salience of peers in adolescence likely makes approval seeking especially important in group situations. Thus, it is not surprising, perhaps, that adolescents are far more likely than are adults to commit crimes in groups (Zimring 1998). Peers also may provide models for behavior that adolescents believe will assist them to accomplish their own ends. For example, there is some evidence that during early and middle adolescence, teens who engage in certain types of antisocial behavior, such as fighting or drinking, may enjoy higher status among their peers as a consequence. Accordingly, some adolescents may engage in antisocial conduct to impress their friends or to conform to peer expectations; indeed, in one of the most influential accounts of so-called adolescence-limited offenders (that is, individuals who commit crimes during adolescence but not before or after), imitation of higher-status peers is hypothesized to be a prime motivation for antisocial behavior (Moffitt 1993).

Future orientation. Future orientation, the capacity and inclination to project events into the future, may also influence judgment because it affects the extent to which individuals consider the long-term consequences of their actions in making choices. Over the course of adolescence and into young adulthood, individuals become more future oriented, with increases in their consideration of future consequences, in their concern about the future, and in their ability to plan ahead (Greene 1986, Nurmi 1991, Steinberg et al. 2008c).

There are several plausible explanations for this age gap in future orientation. In part, adolescents' weaker future orientation may reflect their more limited life experience (Gardner 1993). To a young person, a short-term consequence may have far greater salience than one five years in the future. The latter may seem very remote simply because five years represents a substantial portion of her life. There is also evidence linking the differences between adolescents and adults in future orientation to age differences in brain structure and function, especially in the prefrontal cortex (Cauffman et al. 2005).

Adolescence-limited offenders: antisocial individuals whose offending begins and ends during adolescence

Reward sensitivity. Research evidence also suggests that, relative to adults, adolescents are more sensitive to rewards and, especially, to immediate rewards, a difference that may explain age differences in sensation seeking and risk taking (Galvan et al. 2007, Steinberg et al. 2008a). Although it had once been believed that adolescents and adults differ in risk perception, it now appears that age differences in risk taking are more likely mediated by age differences in reward sensitivity than by age differences in sensitivity to the potential adverse consequences of a risky decision (Cauffman et al. 2008, Millstein & Halpern-Felsher 2002). Thus, adolescents and adults may perceive risks similarly (both in the lab and in the real world) but evaluate rewards differently, especially when the benefits of the risky decision are weighed against the costs. So, for example, in deciding whether to speed while driving a car, adolescents and adults may estimate the risks of this behavior (e.g., being ticketed, getting into an accident) similarly, but adolescents may weigh the potential rewards (e.g., the thrill of driving fast, peer approval, getting to one's destination sooner) more heavily than adults, leading to lower risk ratios for teens—and a higher likelihood of engaging in the (rewarding) activity. Thus, what distinguishes adolescents from adults in this regard is not the fact that teens are less knowledgeable about risks, but rather that they attach greater value to the rewards that risk taking provides (Steinberg 2004).

The heightened salience of rewards to adolescents, relative to adults, is seen in age differences in performance on the Iowa Gambling Task, in which subjects are given four decks of cards, face down, and are instructed to turn over cards, one at a time, from any deck. Each card has information about how much money the subject has won or lost by selecting that card. Two of the decks are "good," in that drawing from them will lead to gains over time, and two of the decks are "bad"; drawing from them will produce net losses. Because a few cards in the "bad" decks offer very high rewards, though, a person who is especially sensitive to rewards will be drawn to the "bad" decks, even if he or she keeps losing money as a result. At the beginning of the task, people tend to draw randomly from all four decks, but as the task progresses, normal adults pick more frequently from the good decks. Children and younger adolescents (as well as adults with damage to the ventromedial prefrontal cortex) do poorly on this task (Crone et al. 2005, Crone & van der Molen 2004, Hooper et al. 2004). Performance improves with age, with the most dramatic improvement taking place during middle adolescence. This likely reflects a decrease in susceptibility to choosing based on the prospect of an immediate, attractive reward. Further evidence that adolescents tend to value immediate rewards more than adults do is seen in age differences in performance on tests of delay discounting, in which individuals are asked to chose between a smaller immediate reward (e.g., receiving $600 tomorrow) and a larger delayed one (e.g., receiving $1000 in one year) (Steinberg et al. 2008c). Heightened reward sensitivity, indexed by self-report or task performance, is especially pronounced during early and middle adolescence, when reward circuitry in the brain is undergoing extensive remodeling. There is some evidence from both human and animal studies that this may be linked to pubertal maturation (Dahl 2004).

Self-regulation. In addition to age differences in susceptibility to peer influence, future orientation, and reward sensitivity, adolescents and adults also differ with respect to their ability to control impulsive behavior and choices. Thus, the widely held stereotype that adolescents are more reckless than adults is supported by research on developmental changes in impulsivity and self-management over the course of adolescence (Galvan et al. 2007, Leshem & Glicksohn 2007). In general, studies show gradual but steady increases in the capacity for self-direction through adolescence, with gains continuing through the high school years and into young adulthood. Similarly, impulsivity, as a general trait, declines linearly between adolescence and adulthood (Steinberg et al. 2008a).

An illustration of behavioral research that sheds light on age differences in impulse control is the study of performance on a task known as the Tower of London. In this test, the subject is presented with an arrangement of colored balls, stacked in a certain order, and several empty vertical rods onto which the balls can be moved. The subject is then presented with a picture of a different configuration of balls and asked to turn the original configuration into the new one by moving one ball at a time, using the fewest number of moves (Berg & Byrd 2002). This task requires thinking ahead, because extra moves must be used to undo a mistake. In several studies, our research group found that early and middle adolescents performed similarly to adults when the problem presented was an easy one (i.e., one that could be solved in two or three moves), but that they did not plan ahead as much as late adolescents and young adults on the harder problems; unlike the older subjects, the younger individuals spent no more time before making their first move on the complex problems than they did on the simple ones (Steinberg et al. 2008a). These findings are consistent with casual observations of teenagers in the real world, which also suggest that they are less likely than are adults to think ahead before acting.

Taken together, these findings from self-report and behavioral studies of psychosocial development indicate that individuals become more resistant to peer influence and oriented to the future, and less drawn to immediate rewards and impulsive, as they mature from adolescence to adulthood. Although the science of adolescent brain development is still in its infancy, finding indicate that much of this maturation continues well beyond the age by which individuals evince adult levels of performance on tests of cognitive capacity. As I discuss in the next section, the continued maturation of cognitive competence through age 16 and the continued maturation of psychosocial competence into young adulthood have important implications for how we view and respond to the criminal behavior of juveniles.

JUVENILE JUSTICE ISSUES INFORMED BY DEVELOPMENTAL SCIENCE

Criminal Culpability of Youth

The adult justice system presumes that defendants who are found guilty are responsible for their own actions, should be held accountable, and should be punished accordingly. Because of the relative immaturity of minors, however, it may not be justified to hold them as accountable as one might hold adults. If, for example, adolescents below a certain age cannot grasp the long-term consequences of their actions or cannot control their impulses, one cannot hold them fully accountable for their actions. In other words, we cannot claim that adolescents "ought to know better" if, in fact, the evidence indicates that they do not know better, or more accurately, cannot know better, because they lack the abilities needed to exercise mature judgment. It is important to note that culpability cannot really be researched directly. Because an individual's culpability is something that is judged by someone else, it is largely in the eye of the beholder. What can be studied, however, are the capabilities and characteristics of individuals that make them potentially blameworthy, such as their ability to behave intentionally or to know right from wrong.

I use the term "culpability" in this review as a shorthand for several interrelated phenomena, including responsibility, accountability, blameworthiness, and punishability. These notions are relevant to the adjudication of an individual's guilt or innocence, because an individual who is not responsible for his or her actions by definition cannot be guilty, and to the determination of a disposition (in juvenile court) or sentence (in criminal court), in that individuals who are found guilty but less than completely blameworthy, owing to any number of mitigating circumstances, merit proportionately less punishment than do guilty individuals who are fully blameworthy.

The starting point in a discussion of criminal culpability is a principle known as penal proportionality. Simply put, penal proportionality holds that criminal punishment should be determined by two criteria: the harm a person causes and his blameworthiness in causing that harm. The law recognizes that different wrongful acts cause different levels of harm through a complex system of offense grading under which more serious crimes (rape, for example) are punished presumptively more severely than less serious crimes (shoplifting, for example). Beyond this, though, two people who engage in the same wrongful conduct may differ in their blameworthiness. A person may be less culpable than other criminals—or not culpable at all—because he inadvertently (rather than purposely) causes the harm, because he is subject to some endogenous deficiency or incapacity that impairs his decision making (such as mental illness), or because he acts in response to an extraordinary external pressure—a gun to the head is the classic example. Less-blameworthy offenders deserve less punishment, and some persons who cause criminal harm deserve no punishment at all (Scott & Steinberg 2008).

The concept of mitigation plays an important role in the law's calculation of blame and punishment, although it gets little attention in the debate about youth crime. Mitigation applies to persons engaging in harmful conduct who are blameworthy enough to meet the minimum threshold of criminal responsibility but who deserve less punishment than a typical offender would receive. Through mitigation, the criminal law calculates culpability and punishment along a continuum and is not limited to the options of full responsibility or complete

Penal proportionality: the principle in American criminal law linking the severity of punishment for a crime to the criminal's culpability

Mitigation: in criminal law, the lessening of criminal responsibility excuse. Indeed, criminal law incorporates calibrated measures of culpability. For example, the law of homicide operates through a grading scheme under which punishment for killing another person varies dramatically depending on the actor's blameworthiness. Thus, the actor who kills intentionally is deemed less culpable if he does so without premeditation because his choice reveals less consideration of the harmful consequences of his act, and the actor who negligently causes another's death is guilty of a less serious crime than one who intends to kill. A person who kills in response to provocation or under extreme emotional disturbance may be guilty only of manslaughter and not of murder. Under standard homicide doctrine, mitigating circumstances and mental states are translated into lower-grade offenses that warrant less punishment.

What makes the conduct of one person less blameworthy than that of another person who causes the same harm? Generally, a person who causes criminal harm is a fully responsible moral agent (and deserves full punishment) if, in choosing to engage in the wrongful conduct, he has the capacity to make a rational decision and a "fair opportunity" to choose not to engage in the harmful conduct. Under this view, the actor whose thinking is substantially impaired or whose freedom is significantly constrained is less culpable than is the typical offender and deserves less punishment—how much less depends on the extent of the impairment or coercion. Under American criminal law, two very different kinds of persons can show that their criminal conduct was less culpable than that of the offender who deserves full punishment—those who are very different from ordinary persons due to impairments that contributed to their criminal choices and those who are ordinary persons whose offenses are responses to extraordinary circumstances or are otherwise aberrant conduct (Scott & Steinberg 2008).

Although it seems paradoxical, adolescents, in a real sense, belong to both groups. In the first group are individuals with endogenous traits or conditions that undermine their decision-making capacity, impairing their ability to understand the nature and consequences of their wrongful acts or to control their conduct. In modern times, this category has been reserved mostly for offenders who suffer from mental illness, mental disability, and other neurological impairments. The criminal law defenses of insanity, diminished capacity, extreme emotional disturbance, and involuntary act recognize that psychological and biological incapacities can undermine decision making in ways that reduce or negate the culpability of criminal choices.

Individuals in the second group are ordinary persons whose criminal conduct is less culpable because it is a response to extraordinary external circumstances: These cases arise when the actor faces a difficult choice, and his response of engaging in the criminal conduct is reasonable under the circumstances, as measured by the likely response of an ordinary law-abiding person in that situation. Thus, under standard self-defense doctrine, a person who kills a threatening assailant is excused from liability if a reasonable person in his place would have felt that his life was in danger. Similarly, the defenses of duress, necessity, and provocation are available to actors who can explain their criminal conduct in terms of unusual external pressures that constrained their ability to choose.

In the preceding section, I described aspects of psychological development in adolescence that are relevant to youthful choices to get involved in criminal activity and that may distinguish young offenders from their adult counterparts. Although youths in mid-adolescence have cognitive capacities for reasoning and understanding that approximate those of adults, even at age 18 adolescents are immature in their psychosocial and emotional development, and this likely affects their decisions about involvement in crime in ways that distinguish them from adults. Teenagers are more susceptible to peer influence than are adults and tend to focus more on rewards and less on risks in making choices. They also tend to focus on short-term rather than long-term consequences and are less capable of anticipating future consequences, and they are more impulsive and volatile in their emotional responses. When we consider these developmental factors within the conventional criminal law framework for assessing blameworthiness, the unsurprising conclusion is that adolescent offenders are less culpable than are adults. The mitigating conditions generally recognized in the criminal law—diminished capacity and coercive circumstances—are relevant to criminal acts of adolescents and often characterize the actions of juvenile offenders. This does not excuse adolescents from criminal responsibility, but it renders them less blameworthy and less deserving of adult punishment.

Although in general lawmakers have paid minimal attention to the mitigating character of adolescents' diminished decision-making capacities, some legislatures and courts have recognized that immature judgment reduces culpability. Most notably, in its consideration of the constitutionality of the juvenile death penalty, the Supreme Court has focused on this rationale for mitigation. In *Roper v. Simmons*, the 2005 case that abolished the juvenile death penalty, the Court adopted the developmental argument for mitigation that follows from the research reviewed above. Justice Kennedy, writing for the majority, described three features of adolescence that distinguish young offenders from their adult counterparts in ways that mitigate culpability—features that are familiar to the reader at this point. The first is the diminished decision-making capacity of youths, which may contribute to a criminal choice that is "not as morally reprehensible as that of adults" because of its developmental nature. The Court pointed to the tendency of adolescents to engage in risky behavior and noted that immaturity and an "underdeveloped sense of responsibility" often result in "impetuous and ill-considered decisions" by youths. Second, the Court pointed to the increased vulnerability of youths to external coercion, including peer pressure. Finally, the Court emphasized that the unformed nature of adolescent identity made it "less supportable to conclude that even a heinous crime was evidence of irretrievably depraved character." Adolescents are less blameworthy than are adults, the Court suggested, because the traits that contribute to criminal conduct are transient, and because most adolescents will outgrow their tendency to get involved in crime as they mature. Although the Court did not elaborate, we have seen that each of these attributes of adolescence corresponds to a conventional source of mitigation in criminal law (*Roper v. Simmons* 2005).

Roper v. Simmons: the U.S. Supreme Court case that abolished the juvenile death penalty

Does this argument apply to the conduct of immature adults? Although most impulsive young risk takers mature into adults with different values, some adult criminals are impulsive, sensation-seeking risk takers who discount future consequences and focus on the here and now. Are these adolescent-like adults also less culpable than other adult offenders and deserving of reduced punishment? I think not. Unlike the typical adolescent, the predispositions, values, and preferences that motivate the adult offenders are not developmental but characterological, and they are unlikely to change merely with the passage of time. Adolescent traits that contribute to criminal conduct are normative of adolescence, but they are not typical in adulthood. In an adult, these traits are often part of the personal identity of an individual who does not respect the values of the criminal law and who deserves punishment when he or she violates its prohibitions (Scott & Steinberg 2008).

Competence of Adolescents to Stand Trial

Before discussing adolescents' competence to stand trial, it is worth underscoring the distinction between competence and culpability—two very different constructs that are often confused, even by those with expertise in criminal law. Competence to stand trial refers to the ability of an individual to function effectively as a defendant in a criminal or delinquency proceeding. In contrast, determinations of culpability focus on the defendant's blameworthiness in engaging in the criminal conduct and on whether and to what extent he will be held responsible. Although many of the same incapacities that excuse or mitigate criminal responsibility may also render a defendant incompetent, the two issues are analytically distinct and

***Dusky v. United States*:** the U.S. Supreme Court case that established criteria for competence to stand trial

***In re Gault*:** the U.S. Supreme Court case that determined that juveniles adjudicated in juvenile court were entitled to many of the same procedural protections as adults adjudicated in criminal court

Developmental incompetence: a lack of competence to stand trial due to normal cognitive or psychosocial immaturity, as opposed to mental illness or disability

separate legal inquiries, and they focus on the defendant's mental state at two different points in time (the time of the crime and the time of the court proceeding).

The reason that competence is required of defendants in criminal proceedings is simple: When the state asserts its power against an individual with the goal of taking away his liberty, the accused must be capable of participating in a meaningful way in the proceeding against him. If a defendant is so mentally ill or disabled that he cannot participate adequately, then the trial lacks fundamental fairness that is required as a part of due process under the Fourteenth Amendment to the U.S. Constitution (Scott & Grisso 2005).

In 1960, the Supreme Court announced a legal standard for trial competence in *Dusky v. United States* that has since been adopted uniformly by American courts. According to *Dusky*, when the issue of a defendant's competence is raised in a criminal trial, the court's determination should focus on "whether the defendant has sufficient present ability to consult with his lawyer with a reasonable degree of rational understanding—and whether he has a rational, as well as factual, understanding of the proceedings against him." Thus, there are two parts to the competence requirement: The defendant must be able to consult with her attorney about planning and making decisions in her defense, and she must understand the charges, the meaning, and purpose of the proceedings and the consequences of conviction (Scott & Grisso 2005).

The requirement that criminal defendants be competent to stand trial had no place in delinquency proceedings in the traditional juvenile court. In a system in which the government's announced purpose was to rehabilitate and not to punish errant youths, the procedural protections accorded adult defendants—including the requirement of adjudicative competence—were thought to be unnecessary. This all changed with *In re Gault*, which led to an extensive restructuring of delinquency proceedings to conform to the requirements of constitutional due process. Today, it is generally accepted that requirements of due process and fundamental fairness are satisfied only if youths facing charges in juvenile court are competent to stand trial.

Until the 1990s, the issue of juveniles' trial competence involved a straightforward incorporation into delinquency proceedings of a procedural protection that was relevant to a relatively small number of mentally impaired adult defendants, where it was assumed to apply similarly to a small number of mentally incapacitated youths. The regulatory reforms that began in the late 1980s changed the situation by increasing the punishment stakes facing many young offenders and by eroding the boundary between the adult and juvenile systems. The importance of this issue was not recognized immediately, however. As legislatures across the country began to enact laws that dramatically altered the landscape of juvenile crime policy, the procedural issue of whether developmentally immature youngsters charged with crimes might be less able to participate in criminal proceedings than are adult defendants—what is referred to in this article as developmental incompetence—was not central to the policy debates.

Given that developmental incompetence largely escaped the attention of courts and policy makers until recently, it is worth asking directly whether the constitutional prohibition against criminal adjudication of incompetent defendants must be applied to this form of incapacity. The answer is surely "yes." The competence requirement is functional at its core, speaking to questions about the impact of cognitive deficiencies on trial participation. Functionally it makes no difference if the defendant cannot understand the proceeding she faces or assist her attorney, whether due to mental illness or to immaturity (Scott & Grisso 2005). In either case, the fairness of the proceeding is undermined. In short, the same concerns that support the prohibition against trying criminal defendants who are incompetent due to mental impairment apply with equal force when immature youths are subject to criminal proceedings. In the context of the recent changes in juvenile justice policy, it has become important to have a better understanding of how the capacities of children and adolescents to participate in criminal proceedings compare with those of adults. In pursuit of this end, I first examine the specific abilities that are required for adjudicative competence under the legal standard. I then turn to the research directly comparing the abilities of juveniles and adults.

Three broad types of abilities are implicated under the *Dusky* standard for competence to stand trial: (*a*) a factual understanding of the proceedings, (*b*) a rational understanding of the proceedings, and (*c*) the ability to assist counsel (Scott & Grisso 2005). Courts applying the standard are directed to weigh each factor, but otherwise they exercise substantial discretion in deciding how much competence is enough. Examining each component of competence under the *Dusky* standard and considering how the capacities of juvenile defendants are likely to compare with those of adults is instructive.

Factual understanding focuses on the defendant's knowledge and awareness of the charges and his understanding of available pleas, possible penalties, the general steps in the adjudication process, the roles of various participants in the pretrial and trial process, and his rights as a defendant. Intellectual immaturity in juveniles may undermine factual understanding, especially given that youths generally have less experience and more limited ability to grasp concepts such as rights. Juveniles also may be more likely than are adults to have extensive deficits in their basic knowledge of the trial process, such that more than brief instruction is needed to attain competence.

The rational understanding requirement of *Dusky* has been interpreted to mean that defendants must comprehend the implications, relevance, or significance of what they understand factually regarding the trial process. Deficits in rational understanding typically involve distorted or erroneous beliefs that nullify factual understanding. For example, an immature defendant may know that he has a right to remain silent, yet believe that the judge can take this "right" away at any time by demanding a response to questions. (When asked what he thought the "right to remain silent" meant, my 12-year-old son said, "It means that you don't have to say anything until the police ask you a question.") Intellectual, emotional, and psychosocial immaturity may undermine the ability of some adolescents to grasp accurately the meaning and significance of matters that they seem to understand factually.

Finally, the requirement that the defendant in a criminal proceeding must have the capacity to assist counsel encompasses three types of abilities. The first is the ability to receive and communicate information adequately to allow counsel to prepare a defense. This ability may be compromised by impairments in attention, memory, and concentration, deficits that might undermine the defendant's ability to respond to instructions or to provide important information to his attorney, such as a coherent account of the events surrounding the offense. As I noted above, these capacities continue to improve through age 16, according to studies of cognitive development. Second, the ability to assist counsel requires a rational perspective regarding the attorney and her role, free of notions or attitudes that could impair the collaborative relationship. For example, some young defendants develop a belief that all adults involved in the proceeding are allied against him, perhaps after seeing defense attorneys and prosecutors chatting together outside the courtroom. Third, defendants must have the capacity to make decisions about pleading and the waiver or assertion of other constitutional rights. These decisions involve not only adequate factual and rational understanding, but also the ability to consider alternatives and make a choice in a decision-making process. Immature youths may lack capacities to process information and exercise reason adequately in making trial decisions, especially when the options are complex and their consequences far reaching.

As juveniles' competence to stand trial began to emerge as an important issue in the mid-1990s, the need for a comprehensive study comparing the abilities of adolescents and adults in this realm became apparent. Before this time, a few small studies had looked at particular capacities in juveniles that were important at different stages in the justice process. However, no comprehensive research had compared the specific capacities of juveniles and adults that are directly implicated in assessments of adjudicative competence. In response to that need, the MacArthur Foundation Research Network on Adolescent Development and Juvenile Justice sponsored a large-scale study of individuals between the ages of 11 and 24—half of whom were in the custody of the justice system and half of whom had never been detained—designed to examine empirically the relationship between developmental immaturity and the abilities of young defendants to participate in their trials (Grisso et al. 2003). The study also probed age differences in psychosocial influences on decision making in the criminal process.

Based on participants' responses to a structured interview that had been used in previous studies of competence to stand trial among mentally ill adults, and for which norms had been established to define clinically significant "impairment," the researchers found that competence-related abilities improve significantly between the ages of 11 and 16. On average, youths aged 11 to 13 demonstrated significantly poorer understanding of trial matters, as well as poorer reasoning and recognition of the relevance of information for a legal defense, than did 14- and 15-year-olds, who in turn performed significantly more poorly than individuals aged 16 and older. There were no differences between the 16- and 17-year-olds and the young adults. The study produced similar results when adolescents and adults were categorized according to their scores above and below the cut-off scores indicating impairment. Nearly one-third of 11- to 13-year-olds and about one-fifth of 14- and 15-year-olds, but only 12% of individuals 16 and older, evidenced impairment at a level comparable to mentally ill adults who had been found incompetent to stand trial with respect to either their ability to reason with facts or understand the trial process. Individual performance did not differ significantly by gender, ethnicity, or, in the detained groups, as a function of the extent of individuals' prior justice system experience. This last finding is important because it indicates that there are components of immaturity independent of a lack of relevant experience that may contribute to elevated rates of incompetence among juveniles.

A different structured interview was used to probe how psychosocial influences affect decision making by assessing participants' choices in three hypothetical legal situations involving a police interrogation, consultation with a defense attorney, and the evaluation of a proffered plea agreement. Significant age differences were found in responses to police interrogation and to the plea agreement. First, youths, including 16- to 17-year-olds, were much more likely to recommend waiving constitutional rights during an interrogation than were adults, with 55% of 11- to 13-year-olds, 40% of 14- to 15-year-olds, and 30% of 16- to 17-year-olds choosing to "talk and admit" involvement in an alleged offense (rather than "remaining silent"), but only 15% of the young adults making this choice. There were also significant age differences in response to the plea agreement. This vignette was styled so as not to clearly favor accepting or rejecting the state's offer, which probably accounted for the fact that young adults were evenly divided in their responses. In contrast, 75% of the 11- to 13-year-olds, 65% of the 14- to 15-year-olds, and 60% of the 16- to 17-year-olds recommended accepting the plea offer. Together, these results suggest a much stronger tendency for adolescents than for young adults to make choices in compliance with the perceived desires of authority figures (Grisso et al. 2003).

Analysis of participants' responses to the vignettes also indicated differences between the youngest age group and older subjects in risk perception and future orientation. Participants were asked to explain their choices, including their perceptions about positive and negative consequences of various options; questions probed the subjects' assessment of the seriousness of risks (the perceived negative consequences) and the likelihood of risks materializing. Analyses indicated age differences for all of these dimensions of "risk perception," with the 11- to 13-year-olds less able to see risks than 16- to 17-year-olds and young adults. Similarly, in comparison with older adolescents, fewer 11- to 13-year-olds mentioned the long-range consequences of their decisions, which suggests that future orientation differences exist that are consistent with those described above.

The study's findings are consistent with those of earlier studies that examined various dimensions of youths' functioning in the justice system. For example, an important study of youths' and adults' capacities to understand Miranda rights in the early 1980s found that, compared with adults in the criminal justice system, 14-year-olds in juvenile detention were less able to understand the meaning and importance of *Miranda* warnings (Grisso 1981). Other studies using smaller samples also have found age differences across the adolescent years with regard to knowledge of legal terms and the legal process in delinquency and criminal proceedings (e.g., Cooper 1997). Finally, a series of studies found significant age differences across the adolescent years in "strategic thinking" about pleas; older adolescents were more likely than younger subjects to make choices that reflected calculations of probabilities and costs based on information provided (e.g., Peterson-Badali & Abramovitch 1993).

In light of what is known about psychological maturation in early and mid-adolescence, these findings are not surprising. Indeed, given the abilities required of defendants in criminal proceedings, it would be puzzling if youths and adults performed similarly on competence-related measures. This research provides powerful and tangible evidence that some youths facing criminal charges may function less capably as criminal defendants than do their adult counterparts. This does not mean, of course, that all youths should be automatically deemed incompetent to stand trial any more than would a psychiatric diagnosis or low IQ score. It does mean, however, that the risk of incompetence is substantially elevated in early and mid-adolescence; it also means that policy makers and practitioners must address developmental incompetence as it affects the treatment of juveniles in court (Scott & Grisso 2005).

It is important to emphasize that the pattern of age differences in studies of legal decision making more closely resembles that seen in studies of cognitive development (where few age differences are apparent after 16) than in studies of psychosocial development (where age differences are observed in late adolescence and sometimes in young adulthood). This suggests that determinations of where to draw a legal boundary between adolescence and adulthood must be domain specific. In matters in which cognitive abilities predominate, and where psychosocial factors are of minimal importance (that is, in situations where the influence of adolescents' impulsivity, susceptibility to peer pressure, reward sensitivity, and relatively weaker future orientation is mitigated), adolescents older than 15 should probably be treated like adults. In situations in which psychosocial factors are substantially more important, drawing the boundary at an older age is more appropriate. This is why my colleagues and I have argued that it is perfectly reasonable to have a lower boundary for adolescents' autonomous access to abortion (a situation in which mandatory waiting periods limit the impact of impulsivity and shortsightedness and where consultation with adults likely counters immaturity of judgment) than for judgments of criminal responsibility (because adolescents' crimes are often impulsive and influenced by peers) (Steinberg et al. 2008b).

Impact of Punitive Sanctions on Adolescent Development and Behavior

As noted above, the increasingly punitive orientation of the justice system toward juvenile offenders has resulted in an increase in the number of juveniles tried and sanctioned as adults and in the use of harsher sanctions in responding to the delinquent behavior of juveniles who have been retained in the juvenile justice

Life-course-persistent offenders: antisocial individuals whose offending begins before adolescence and persists into adulthood

Age-crime curve: in criminology, the relation between age and crime, showing that the prevalence of criminal activity increases between preadolescence and late adolescence, peaks around age 17, and declines thereafter

system. Research on the impact of adult prosecution and punishment and on the use of punitive sanctions more generally suggests, however, that these policies and practices may actually increase recidivism and jeopardize the development and mental health of juveniles (Fagan 2008). Consequently, there is a growing consensus among social scientists that policies and practices, such as setting the minimum age of criminal court jurisdiction below 18 (as about one-third of all states currently do), transferring juveniles to the adult system for a wide range of crimes, including nonviolent crimes, relying on incarceration as a primary means of crime control, and exposing juvenile offenders to punitive programs such as boot camps, likely do more harm than good, cost taxpayers much more than they need spend on crime prevention, and ultimately pose a threat to public safety (Greenwood 2006).

In order to understand why this is the case, it is important to begin with a distinction between adolescence-limited and life-course-persistent offenders (Moffitt 1993). Dozens of longitudinal studies have shown that the vast majority of adolescents who commit antisocial acts desist from such activity as they mature into adulthood and that only a small percentage—between five and ten percent, according to most studies—become chronic offenders. Thus, nearly all juvenile offenders are adolescent limited. This observation is borne out in inspection of what criminologists refer to as the age-crime curve, which shows that the incidence of criminal activity increases between preadolescence and late adolescence, peaks at about age 17 (slightly younger for nonviolent crimes and slightly older for violent ones), and declines thereafter. These findings, at both the individual and aggregate level, have emerged from many studies that have been conducted in different historical epochs and around the world (Piquero et al. 2003).

In view of the fact that most juvenile offenders mature out of crime (and that most will desist whether or not they are caught, arrested, prosecuted, or sanctioned), one must therefore ask how to best hold delinquent youth responsible for their actions and deter future crime (both their own and that of others) without adversely affecting their mental health, psychological development, and successful transition into adult roles. If the sanctions to which juvenile offenders are exposed create psychological disturbance, stunt the development of cognitive growth and psychosocial maturity, and interfere with the completion of schooling and entrance into the labor force, these policies are likely to exacerbate rather than ameliorate many of the very factors that lead juveniles to commit crimes in the first place (mental illness, difficulties in school or work, and, as reviewed above, psychological immaturity).

It is clear that sanctioning adolescents as adults is counterproductive. One group of researchers examining this question compared a group of 2700 Florida youths transferred to criminal court, mostly based on prosecutors' discretionary authority under Florida's direct-file statute, with a matched group of youths retained in the juvenile system (Bishop & Frazier 2000). In another study, the researchers compared 15- and 16-year-olds charged with robbery and burglary in several counties in metropolitan New York and in demographically similar counties in New Jersey. The legal settings differed in that New York juveniles age 15 and older who are charged with robbery and burglary are automatically dealt with in the adult system under that state's legislative waiver statute, whereas in New Jersey, transfer is rarely used, and the juvenile court retains jurisdiction over almost all youths charged with these crimes (Fagan 1996).

The New York-New Jersey study found that youths convicted of robbery in criminal court were rearrested and incarcerated at a higher rate than those who were dealt with in the juvenile system, but that rates were comparable for burglary, a less serious crime. The study also examined the number of days until rearrest and found a similar pattern; the youths sentenced for robbery in criminal court reoffended sooner than did their juvenile court counterparts. Recidivism was not affected by sentence length; longer sentences were not more effective at reducing recidivism than were shorter sentences. Results of the Florida study also support the conclusion that juvenile sanctions may reduce recidivism more effectively than criminal punishment. This study measured only rearrest rates and found lower rates for youths who were retained in juvenile court than for youths who were transferred. The follow-up period in this study was relatively brief—less than two years. During this period, transferred youth were more likely to be rearrested, committed more offenses per year, and reoffended sooner than did juveniles in the juvenile system. As in the New York-New Jersey study, longer sentences did not have a deterrent effect.

Within the juvenile system, of course, there is wide variation in the types and severity of sanctions to which offenders are exposed. Some youths are incarcerated in prison-like training schools, whereas others receive loosely supervised community probation—neither of which is effective at changing antisocial behavior. An important question therefore is, what can the juvenile system offer young offenders that will be effective at reducing recidivism? A detailed discussion of the enormous literature evaluating the effects of various sanctions and interventions is beyond the scope of this review, and this literature has been summarized many times (Greenwood 2006, Lipsey 1999). Here I highlight a few main points.

Until the 1990s, most researchers who study juvenile delinquency programs might well have answered that the system had little to offer in the way of effective therapeutic interventions; the dominant view held by social scientists in the 1970s and 1980s was that "nothing works" to reduce recidivism with young offenders. Today the picture is considerably brighter, in large part due to a substantial body of research produced over the past 15 years showing that many juvenile programs, in both community and institutional settings, have a substantial crime-reduction effect; for the most promising programs, that effect is in the range of 20% to 30%. An increased focus on research-based programs and on careful outcome evaluation allows policy makers to assess accurately the impact on recidivism rates of particular programs to determine whether the economic costs are justified. In a real sense, these developments have revived rehabilitation as a realistic goal of juvenile justice interventions.

In general, successful programs are those that attend to the lessons of developmental psychology, seeking to provide young offenders with supportive social contexts and to assist them in acquiring the skills necessary to change problem behavior and to attain psychosocial maturity. In his comprehensive meta-analysis of 400 juvenile programs, Lipsey (1995) found that among the most effective programs in both community and institutional settings were those that focused on improving social development skills in the areas of interpersonal relations, self-control, academic performance, and job skills. Some effective programs focus directly on developing skills to avoid antisocial behavior, often through cognitive behavioral therapy. Other interventions that have been shown to have a positive effect on crime reduction focus on strengthening family support, including Multisystemic Therapy, Functional Family Therapy, and Multidimensional Treatment Foster Care, all of which are both effective and cost effective (Greenwood 2006). It is also clear from these reviews that punitive sanctions administered within the juvenile system have iatrogenic effects similar to those seen in studies of juveniles tried as adults. Punishment-oriented approaches, such as "Scared Straight" or military-style boot camps, do not deter future crime and may even inadvertently promote reoffending. Nor do these programs appear to deter other adolescents from offending (Greenwood 2006).

The dearth of evidence supporting the effectiveness of tough sanctions in deterring youthful criminal activity becomes less puzzling when we consider the response of young offenders to harsh punishment in light of developmental knowledge about adolescence discussed earlier. Teenagers on the street deciding whether to hold up a convenience store may simply be less capable than adults, due to their psychosocial immaturity, of considering the sanctions they will face. Thus, the developmental influences on decision making that mitigate culpability also may make adolescents less responsive to the threat of criminal sanctions (Scott & Steinberg 2008).

In addition, adolescence is a formative period of development. In mid and late adolescence, individuals normally make substantial progress in acquiring and coordinating skills that are essential to filling the conventional roles of adulthood. First, they begin to develop basic educational and vocational skills to enable them to function in the workplace as productive members of society. Second, they also acquire the social skills necessary to establish stable intimate relationships and to cooperate in groups. Finally, they must begin to learn to behave responsibly without external supervision and to set meaningful personal goals for themselves. For most individuals, the process of completing these developmental tasks extends into early adulthood, but making substantial progress during the formative stage of adolescence is important. This process of development toward psychosocial maturity is one of reciprocal interaction between the individual and her social context. Several environmental conditions are particularly important, such as the presence of an authoritative parent or guardian, association with prosocial peers, and participation in educational, extracurricular, or employment activities that facilitate the development of autonomous decision making and critical thinking. For the youth in the justice system, the correctional setting becomes the environment for social development and may affect whether he acquires the skills necessary to function successfully in conventional adult roles (Steinberg et al. 2004).

Normative teenagers who get involved in crime do so, in part, because their choices are driven by developmental influences typical of adolescence. In theory, they should desist from criminal behavior and mature into reasonably responsible adults as they attain psychosocial maturity—and most do, especially as they enter into adult work and family responsibilities. Whether youths successfully make the transition to adulthood, however, depends in part on whether their social context provides opportunity structures for the completion of the developmental tasks described above. The correctional environment may influence the trajectories of normative adolescents in the justice system in important ways. Factors such as the availability (or lack) of good educational, skill building, and rehabilitative programs; the attitudes and roles of adult supervisors; and the identity and behavior of other offenders shape the social context of youths in both the adult and the juvenile systems. These factors may affect the inclination of young offenders to desist or persist in their criminal activities and may facilitate or impede their development into adults who can function adequately in society—in the workplace, in marriage or other intimate unions, and as citizens.

SUMMARY AND CONCLUDING COMMENTS

The overarching question I pose in this article is whether research on adolescent development indicates that adolescents and adults differ in ways that warrant their differential treatment when they violate the law. More specifically, I ask how this research informs debate about three fundamental questions that continue to challenge the justice system: (*a*) Should adolescents be held to adult standards of criminal culpability and, accordingly, exposed to the same punishment as adults; (*b*) Do adolescents possess the necessary capabilities to function as competent defendants in an adversarial court proceeding; and (*c*) How are juvenile offenders affected by the sorts of punitive sanctions that became increasingly popular during the past several decades?

It is now incontrovertible that psychological development continues throughout adolescence and into young adulthood in ways that are relevant to all three questions. Although basic cognitive competence matures by the time individuals reach age 16, many of the social and emotional capacities that influence adolescents' judgment and decision making, especially outside the psychologist's laboratory, continue to mature into late adolescence and beyond. Compared to individuals in their mid to late twenties, adolescents even as old as 18 are more impulsive, less oriented to the future, and more susceptible to the influence of their peers. In addition, because adolescence is also period during which individuals are still acquiring the psychological capacities they will need to successfully transition into adult work and family roles, it is important that the sanctions to which juvenile offenders are exposed not adversely affect their development. Recent research on the neural underpinnings of these developments does not change the portrait of adolescent immaturity painted by behavioral research, but it does add detail and support to the argument that makes the story more compelling. It is one thing to say that adolescents don't control their impulses, stand up to peer pressure, or think through the consequences of their actions as well as adults; it is quite another to say that don't because they can't.

Because American criminal law clearly provides that diminished judgment mitigates criminal responsibility, it is reasonable to argue that adolescents are inherently less blameworthy than their elders in ways should affect decisions about criminal punishment; as a class, adolescents are inherently less blameworthy than adults. The picture that emerges from an analysis of the capacities necessary for competence to stand trial is not the same, however. Here the relevant research indicates that some adolescents (generally, those 16 and older) have adult-like capabilities but that others (generally those 15 and younger) may not. Research on the impact of punitive sanctions on adolescent development and behavior, although not explicitly developmental in nature, indicates that trying adolescents as adults or exposing them to especially harsh sanctions does little to deter offending and may indeed have iatrogenic effects.

Although justice system policy and practice cannot, and should not, be dictated solely by studies of adolescent development, the ways in which we respond to juvenile offending should at the very least be informed by the lessons of developmental science. Taken together, the lessons of developmental science offer strong support for the maintenance of a separate juvenile justice system in which adolescents are judged, tried, and sanctioned in developmentally appropriate ways. Using developmental science to inform juvenile justice policy is not a panacea that will solve the problem of youth crime. Adolescents will always get in trouble, sometimes very serious trouble, and some will continue to offend, despite the state's best efforts to respond to their crimes in ways that will deter future offending. At the same time, the future prospects of some youths will be harmed by a system that holds them to adult levels of accountability for their crimes under our transfer rules. No one policy regime will yield good outcomes for all young offenders, but looking to developmental research to guide our decision making provides a solid framework for policies and practices that will enhance public safety in the long run by promoting healthy adolescent development.

SUMMARY POINTS

1. During the past two decades, policies and practices concerning the treatment of juvenile offenders in the United States became increasingly punitive, as evidenced by the increase in the number of juveniles tried as adults and the expanded use of harsh sanctions within both the juvenile and criminal justice systems. This was a break from the traditional model of juvenile justice, which emphasized rehabilitation rather than punishment as its core purpose, that had prevailed for most of the twentieth century.

2. In order to make well-informed decisions about the treatment of juveniles who have entered the juvenile justice pipeline, therefore, policymakers, practitioners, and mental health professionals need to be familiar with the developmental changes that occur during childhood and adolescence in the capabilities and characteristics that are relevant to their competence to stand trial, their criminal culpability, and their likely response to treatment.
3. Brain maturation continues well into young adulthood, and although individuals, on average, perform at adult levels on tests of basic cognitive ability by the time they are 16, most do not attain adult-like levels of social and emotional maturity until very late in adolescence or early in adulthood. Compared to adults, adolescents are more susceptible to peer influence, less oriented to the future, more sensitive to short-term rewards, and more impulsive.
4. This research on adolescent brain, cognitive, and psychosocial development supports the view that adolescents are fundamentally different from adults in ways that warrant their differential treatment in the justice system. An analysis of factors that mitigate criminal responsibility under the law indicates that adolescents are inherently less culpable than are adults and should therefore be punished less severely. In addition, studies of competence to stand trial indicate that those who are under 16 are more likely to be incompetent than are adults, raising questions about the appropriateness of trying younger adolescents in criminal court.
5. Studies of the impact of punitive sanctions on adolescent development and behavior, including prosecuting and sanctioning adolescents as adults, indicate that they do not deter adolescents from breaking the law and may in fact increase recidivism. In contrast, family-based interventions have been shown to be both effective and cost effective.

DISCLOSURE STATEMENT

The author is not aware of any biases that might be perceived as affecting the objectivity of this review.

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The Adolescent Brain

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Adolescence is a developmental period characterized by suboptimal decisions and actions that are associated with an increased incidence of unintentional injuries, violence, substance abuse, unintended pregnancy, and sexually transmitted diseases. Traditional neurobiological and cognitive explanations for adolescent behavior have failed to account for the nonlinear changes in behavior observed during adolescence, relative to both childhood and adulthood. This review provides a biologically plausible model of the neural mechanisms underlying these nonlinear changes in behavior. We provide evidence from recent human brain imaging and animal studies that there is a heightened responsiveness to incentives and socioemotional contexts during this time, when impulse control is still relatively immature. These findings suggest differential development of bottom-up limbic systems, implicated in incentive and emotional processing, to top-down control systems during adolescence as compared to childhood and adulthood. This developmental pattern may be exacerbated in those adolescents prone to emotional reactivity, increasing the likelihood of poor outcomes.

Key words: **adolescence; prefrontal cortex; nucleus accumbens; amygdala; limbic; impulsivity; reward; development; risk taking; emotion**

Introduction

Adolescence is the period between childhood and adulthood encompassed by changes in physical, psychological, and social development (Ernst et al. 2006). These alterations make this period a time of vulnerability and adjustment (Steinberg 2005). According to the National Center for Health Statistics, there are over 13,000 adolescent deaths in the United States each year. Approximately 70% of these deaths result from motor vehicle crashes, unintentional injuries, homicide, and suicide (Eaton et al. 2006). Results from the 2005 National Youth Risk Behavior Survey (YRBS) show that adolescents engage in behaviors that increase their likelihood of death or illness by driving a vehicle after drinking or without a seat belt, carrying weapons, using illegal substances, and engaging in unprotected sex resulting in unintended pregnancies and STDs, including HIV infection (Eaton et al. 2006). These statistics underscore the importance of understanding risky choices and behavior in adolescents.

Adolescence is also a time of increased emotional reactivity. During this period, the social environment is changing such that more time is spent with peers versus adults, and more conflicts arise between the adolescent and his/her parents (Csikszentmihalyi et al. 1977; Steinberg 1989). These changes in social interactions may influence the rise of emotional reactivity. In addition, given the increase in risky choices and behavior during adolescence, it appears the value of positive and negative information may be exaggerated. Greater emotional reactivity and sensitivity during adolescence may play a role in the higher incidence of affective disorder onset and addiction during this developmental period (Pine et al. 2001; Silveri et al. 2004; Steinberg 2005).

A number of cognitive and neurobiological hypotheses have been postulated to explain why adolescents engage in suboptimal choice behavior. In a recent review of the literature on human adolescent brain development, Yurgelun-Todd (2007) suggests that cognitive development during adolescence is associated with progressively greater efficiency of cognitive control and affective modulation. An increase in activity in the prefrontal regions as an indication of maturation (Rubia et al. 2000; Rubia et al. 2006; Tamm et al. 2002) and diminished activity in irrelevant brain regions (Brown et al. 2005; Durston et al. 2006; Monk

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et al. 2003) are described as the neurobiological explanation for the behavioral changes associated with adolescence. This general pattern, of improved cognitive control and emotion regulation with maturation of the prefrontal cortex, suggests a linear increase in development from childhood to adulthood.

As evidenced by the National Center for Health Statistics on adolescent behavior and mortality, suboptimal choices and actions observed during adolescence represent a nonlinear change in behavior, distinct from childhood and adulthood. If immaturity of prefrontal cortex were the basis for suboptimal choice behavior and heightened emotional reactivity in adolescence, then children who have less developed prefrontal cortex and cognitive abilities should look remarkably similar or even worse than adolescents. Thus, immature prefrontal function alone cannot account for adolescent behavior.

This review will provide evidence from developmental animal and human neuroimaging studies that may account for nonlinear changes in behavior and development during adolescence. A model of adolescent brain development is presented in the context of risk factors including suboptimal decision making and heightened emotional reactivity.

Development of Goal-directed Behavior: Risk versus Impulse

An accurate conceptualization of cognitive and neurobiological changes during adolescence must treat adolescence as a transitional developmental period (Spear 2000), rather than a single snapshot in time (Casey et al. 2005). In other words, to understand this developmental period, transitions into and out of adolescence are necessary for distinguishing distinct attributes of this stage of development. Adolescent behavior has been described as impulsive and risky, almost synonymously, yet these behaviors rely on different cognitive and neural processes (Casey et al. in press), which suggest distinct constructs with different developmental trajectories.

A cornerstone of cognitive development is the ability to suppress inappropriate thoughts and actions in favor of goal-directed ones, especially in the presence of compelling incentives (Casey et al. 2005; Casey et al. 2000; Casey et al. 2002). A number of classic developmental studies have shown that this ability develops throughout childhood and adolescence (Case 1972; Flavell et al. 1966; Keating & Bobbitt 1978; Pascual-Leone 1970). Several theorists (e.g., Bjorkland 1985, 1987; Case 1985) have argued that cognitive development is due to increases in processing speed and efficiency and not due to an increase in mental capacity. Other theorists have included the construct of "inhibitory" processes in their account of cognitive development (Harnishfeger & Bjorkland 1993). According to this account, immature cognition is characterized by susceptibility to interference from competing sources that must be suppressed (e.g., Brainerd & Reyna 1993; Dempster 1993) (Casey et al. 2002; Diamond 1985; Munakata & Yerys 2001).. Thus goal-directed behavior requires the control of impulses or delay of gratification for optimization of outcomes, and this ability appears to mature across childhood and adolescence.

On a cognitive or behavioral level, the immature cognition of adolescence is characterized as impulsive (i.e., lacking cognitive control) and risk taking, with these constructs used synonymously and without appreciation for distinct developmental trajectories for each. Human imaging and animal studies suggest distinct neurobiological and developmental trajectories for the neural systems that underlie these separate constructs of impulse control and risky decisions. Specifically, a review of the literature suggests that impulsivity diminishes with age across childhood and adolescence (Casey et al. 2005; Casey et al. 2002; Galvan et al. 2007) and is associated with protracted development of the prefrontal cortex (Casey et al. 2005; Casey et al. 2002; Galvan et al. 2007) and is associated with protracted development of the prefrontal cortex (Casey et al. 2005). However, there are individual differences in the degree of impulsivity, regardless of age.

In contrast to the linear increase with age associated with impulse control, risk taking appears greater during adolescence relative to childhood and adulthood and is associated with subcortical systems known to be involved in evaluation of incentives and affective information. Human imaging studies that are reviewed here suggest an increase in subcortical activation (accumbens and amygdala) when making risky choices and processing emotional information (Ernst et al. 2005; Monk et al. 2003; Montague & Berns 2002) (Kuhnen & Knutson 2005; Matthews et al. 2004) that is exaggerated in adolescents, relative to children and adults (Ernst et al. 2005; Galvan et al. 2006).

These findings suggest distinct neurobiological trajectories for impulse versus risk taking behavior. The limbic subcortical systems appear to be developed by adolescence in contrast to control systems that show a protracted and linear developmental course into young adulthood. The prefrontal cortical control systems are necessary for overriding inappropriate choices and actions in favor of goal-directed ones.

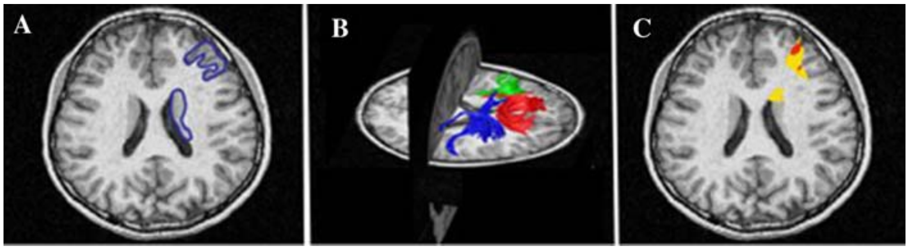

FIGURE 1. Illustrations of the most common magnetic resonance methods used in the study of human development. **(A)** Structural magnetic resonance imaging (MRI) to produce structural images of the brain useful for anatomical and morphometric studies, **(B)** diffusion tensor imaging (DTI) measures myelination and directionality of fiber tracts between anatomical structures, and **(C)** functional MRI (fMRI) measures patterns of brain activity within those structures (from Casey et al. 2005).

Animal Studies of Adolescent Brain Development

Until recently, much of our understanding of the adolescent brain has come from animal studies. These experiments have been critical for obtaining information about the neurochemical and cellular changes that occur as a function of age. The validity of animal models to study adolescence has been questioned, since it is argued that only humans undergo the psychological stress of adolescence (e.g., Bogin 1994). However, animals including rodents and nonhuman primates exhibit increased social interactions during adolescence (Primus & Kellogg 1989) as well as novelty-seeking and risk-taking behaviors (Adriani et al. 1998; Spear 2000). These behavioral findings suggest that animal models are appropriate for studying neurobiological changes during adolescence.

Studies in rodents have shown at the cellular level that there are distinct changes in limbic and prefrontal regions during adolescence. During early puberty, there is an overproduction of axons and synapses, followed by rapid pruning in later adolescence (Crews et al. 2007). Specifically, there is dendritic pruning in the amygdala (Zehr et al. 2006), nucleus accumbens (Teicher et al. 1995), and prefrontal cortex (Andersen & Teicher 2004; Andersen et al. 2000) and continual growth in the density of the fibers connecting the amygdala and prefrontal cortex into early adulthood (Cunningham et al. 2002). There is more prolonged pruning throughout adolescence in the prefrontal cortex versus the accumbens (Andersen et al. 2000; Teicher et al. 1995). These differences in pruning in rodents are consistent with our model suggesting that the accumbens matures earlier than the prefrontal cortex.

Consistent with the cellular changes in animals, there are alterations in neurotransmission in these subcortical and cortical areas. Animal studies have shown that dopamine is crucial for communication between the accumbens, amygdala, and prefrontal cortex and that signaling between these regions relies upon the fine balance between excitatory and inhibitory dopamine transmission (Floresco & Tse 2007; Grace et al. 2007; Jackson et al. 2001). There are significant peaks in dopamine expression during adolescence. Dopamine projections to the prefrontal cortex continue to develop into early adulthood, with dopamine levels peaking in the prefrontal cortex during adolescence versus earlier or later in life in nonhuman primates (Rosenberg & Lewis 1994, 1995) and in rats (Kalsbeek et al. 1988). Dopamine receptor expression is highest in the accumbens during early adolescence (Tarazi et al. 1998). These findings in rodents suggest that there are specific regions undergoing structural changes, and therefore, connections and communication between subcortical and cortical regions are in transition and in flux during adolescence. Significant evidence suggests that the neuroanatomical changes described above are also occurring during adolescence in humans, but our methods for studying humans only provide an approximate index of such changes.

Neuroimaging Studies of Human Brain Development

Our current understanding of the human adolescent brain has come from advances in neuroimaging methodologies that can be used with developing human populations. These methods depend on magnetic resonance imaging (MRI) methods (see FIG. 1) and include structural MRI, which is used to measure the size and shape of structures; diffusion tensor imaging (DTI), which is used to index connectivity of white matter fiber tracts; and functional MRI which is used to

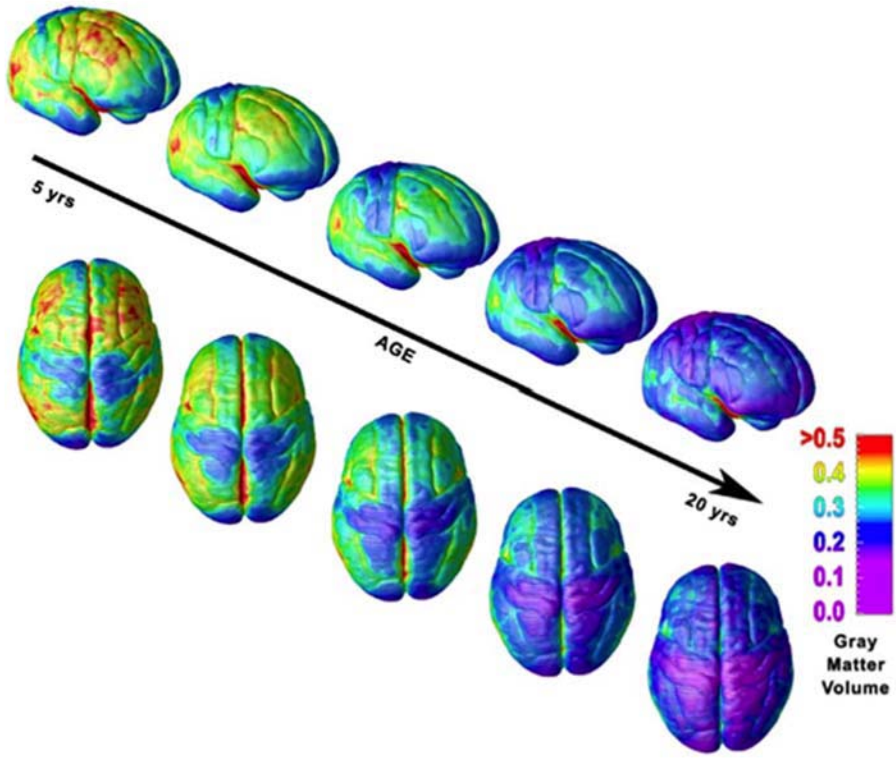

FIGURE 2. Illustration of gray matter volume maturation over the cortical surface from 5 to 20 years of age (from Lenroot & Giedd 2006).

measure patterns of brain activity. These methods have furthered our understanding of the neurobiological basis and development of reward or incentive behavior relative to goal-directed behavior.

MRI Studies of Human Brain Development

Several studies have used structural MRI to map the developmental course of the normal brain (for review, see Durston et al. 2001). Although the brain reaches approximately 90% of its adult size by age six, the gray and white matter subcomponents of the brain continue to undergo dynamic changes throughout adolescence. Data from recent longitudinal MRI studies indicate that the change in gray matter volume over time has an inverted U-shape pattern and has greater regional variation than white matter (Giedd 2004; Gogtay et al. 2004, Sowell et al. 2003, 2004). In general, regions that involve primary functions, such as motor and sensory systems, mature earliest compared to the higher-order association areas that integrate these primary functions (Gogtay et al. 2004; Sowell et al. 2004). MRI studies show loss of cortical gray matter first in primary sensorimotor areas, followed by that in the dorsolateral prefrontal and lateral temporal cortices (Gogtay et al. 2004) (see Fig. 2). This pattern of change is consistent with nonhuman primate (Bourgeois et al. 1994) and human postmortem studies (Huttenlocher 1979) indicating that the prefrontal cortex is one of the last brain regions to mature. In contrast to gray matter, white matter volume increases in a roughly linear pattern throughout development and into adulthood (Gogtay et al. 2004). These changes most likely reflect ongoing myelination of axons by oligodendrocytes enhancing neuronal conduction and communication.

When examining neuroanatomical changes across development, the subcortical regions are often overlooked, however, it is important to note that these areas have some of the largest changes during development in the brain, particularly in the basal ganglia (Sowell et al. 1999) and specifically in males (Caviness et al. 1996; Giedd et al. 1996; Reiss et al. 1996). Developmental changes in structural volume within basal ganglia and prefrontal regions are interesting in light of the previously mentioned animal work showing pruning in these regions during adolescence. These processes allow for the fine tuning and strengthening of connections between prefrontal and subcortical regions during development and learning that may correspond to greater cognitive control.

How do these changes in structure relate to differences in cognition? A number of studies have related frontal lobe structural maturation and cognitive function using neuropsychological and cognitive measures (e.g., Sowell et al. 2003). Specifically, these studies showed associations between MRI-based regional volumes of the prefrontal cortex and basal ganglia with measures of cognitive control (i.e., ability to override an inappropriate response in favor of another or to suppress attention toward irrelevant stimulus attribute in favor of relevant stimulus attribute) (Casey et al. 1997, 1997). These findings suggest that cognitive changes are reflected in structural brain changes and underscore the importance of subcortical (basal ganglia) as well as cortical (e.g., prefrontal cortex) development. While these findings showed associations between structure and function, a more in-depth discussion of functional imaging evidence for changes in activity that more directly coincide with behavior across development is presented in the fMRI section.

DTI Studies of Human Brain Development

The MRI-based morphometry studies previously reviewed suggest that during development, cortical connections are fine tuned via elimination of an overabundance of synapses and by strengthening of relevant connections, although these measures do not have the resolution to visualize or measure synapses. Recent advances in MRI technology, like DTI, provide a potential tool for examining the role of specific white matter tracts in the development of the brain and behavior (for review, see Cascio et al. 2007). Examining white matter tracts can provide knowledge about pathways of connectivity in the brain, and presumably it is via these pathways that information is able to travel from one region of the brain to another (Cascio et al. 2007). Relevant to this paper are the neuroimaging studies that have linked the development of white matter fiber tracts with improvements in cognitive ability with age.

Recently, associations have been shown between DTI-based measures of prefrontal white matter development and cognition in children. Nagy and colleagues showed a positive correlation between maturation of prefrontal–parietal fiber tracts and working memory in children (Nagy et al. 2004), which is consistent with functional neuroimaging studies showing differential recruitment of these regions in children relative to adults. Using a similar approach, Liston and colleagues (2006) have shown that white matter tracts between prefrontal–basal ganglia and posterior fiber tracts continue to develop across childhood into adulthood, but only tracts between the prefrontal cortex and basal ganglia are correlated with impulse control, as measured by performance on a go/no-go task. The prefrontal fiber tracts were defined by regions of interests, which were identified in an fMRI study using the go/no-go task. In developmental DTI studies, fiber tract measures were correlated with age, but specificity of particular fiber tracts with cognitive performance were shown by dissociating the particular tract (Liston et al. 2006) or cognitive ability (Nagy et al. 2004). These findings highlight the importance of examining not only regional, but also related circuitry changes, when making inferences about neural changes in cognition across development.

Functional MRI Studies of Human Brain Development

Compared to MRI and DTI, fMRI is a more direct approach for examining behavior changes during development and for establishing structure–function relationships. Using fMRI to measure functional changes in the developing brain has significant potential for the field of developmental science and provides a means for constraining interpretations of adolescent behavior.

As stated previously, the development of the prefrontal cortex is believed to play an important role in the maturation of higher cognitive abilities such as decision making and cognitive control (Casey et al. 2002; Casey et al. 1997; Hare & Casey 2005). Many behavioral paradigms, together with fMRI, have assessed the neurobiological basis of these abilities, including flanker, Stroop, and go/no-go tasks (Casey et al. 1997; Casey et al. 2000; Durston et al. 2003). Collectively, these studies show that children recruit distinct but often larger and more diffuse prefrontal regions when performing these tasks than do adults. The patterns of brain activity that are important for task performance, such as those regions that correlate with cognitive performance, become more fine tuned with age. Regions that are not correlated with task performance diminish in activity with age. This pattern has been observed across both cross-sectional (Brown et al. 2005) and longitudinal studies (Durston et al. 2006) and across a variety of paradigms. Neuroimaging studies cannot definitively characterize the mechanism of such developmental changes as dendritic arborization or synaptic pruning. However, these studies suggest that change over a period of time results in both refinement within brain regions as well as fine tuning of projections from these regions (Brown et al. 2005; Bunge et al. 2002; Casey et al. 1997; Casey et al. 2002; Luna et al. 2001; Moses et al. 2002; Schlaggar et al. 2002; Tamm et al. 2002; Thomas et al. 2004; Turkeltaub et al. 2003).

Functional MRI Studies of Behavior during Adolescence

The question remains how can fMRI studies help explain whether adolescents, compared to children or adults, are 1) lacking sufficient cognitive control (impulsive), 2) risky in their choices and actions, and 3) more sensitive to affective information when required to exert cognitive control than children or adults.

Impulse control, as measured by cognitive control tasks like the go/no-go task, shows a linear pattern of development across childhood and adolescence, as described above. However, we were interested in understanding changes across development in top-down control regions and subcortical reward-seeking regions. It is only recently that risk taking in adolescents has been examined with neuroimaging techniques (Ernst et al. 2005; May et al. 2004). These studies have focused primarily on the region of the accumbens, a portion of the basal ganglia involved in predicting reward outcomes. Although two recent reports showed less ventral prefrontal activity (Eshel et al. 2007) and posterior mesofrontal activity (Bjork et al. 2007) in adolescents versus adults on risk-taking behavior, the goal of our studies was to characterize the development of limbic subcortical regions involved in motivation and emotional reactivity in conjunction with top-down control regions (prefrontal cortex). Many studies have examined the neural response in children and adolescents to affective information (e.g., emotional faces) (Baird et al. 1999; Killgore et al. 2001; Monk et al. 2003; Thomas et al. 2001b; Yurgelun-Todd & Killgore 2006) but typically have used passive viewing or attention tasks (Monk et al. 2003) unrelated to processing of the affective information. Our studies examine how affect influences cognitive control across development and characterizes the activation of the subcortical systems (amygdala) involved in affect regulation relative to the cortical (prefrontal) regions associated with cognitive control.

A Neurobiological Model of Adolescence

How do neural changes in subcortical regions (e.g., accumbens and amygdala) associated with reward-seeking and emotion coincide with development of the prefrontal regions and do they relate to impulsivity and risk-taking behaviors? We have developed a neurobiological model of adolescent development within this framework that builds on rodent models (Laviola et al. 1999; Spear 2000) and recent imaging studies of children, adolescents, and adults (Ernst et al. 2005; Galvan et al. 2007; Galvan et al. 2006; Hare & Casey, in press). FIGURE 3 depicts this model illustrating how bottom-up limbic and prefrontal top-down control regions should be considered together. The graph shows different developmental trajectories for these systems, with limbic systems developing earlier than prefrontal control regions. According to this model, the individual is biased more by functionally mature limbic regions during adolescence (i.e., imbalance of limbic relative to prefrontal control), compared to children, for whom these systems are both still developing, and compared to adults, for whom these systems are fully mature. This perspective provides a basis for nonlinear shifts in behavior across development, due to earlier maturation of this limbic system relative to the less mature top-down prefrontal control region. Furthermore, with development and experience, the functional connectivity between these regions provides a mechanism for top-down control of these regions (Hare & Casey, in press). Our model reconciles the contradiction between health statistics of risky behavior during adolescence and the astute observation by Reyna and Farley (2006) that adolescents are able to reason and understand risks of behaviors in which they engage.

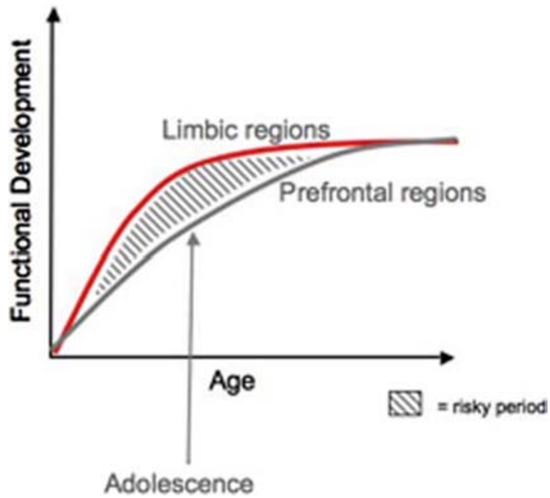

FIGURE 3. The traditional explanation of adolescent behavior has been that it is due to the protracted development of the prefrontal cortex. Our model takes into consideration the development of the prefrontal cortex together with subcortical limbic regions (e.g., nucleus accumbens and amygdala) that have been implicated in risky choices and emotional reactivity.

According to our model, in emotionally salient situations, the more mature limbic system will win over the prefrontal control system. In other words, when a poor decision is made in an emotional context, the adolescent may know better, but the salience of the emotional context biases his or her behavior in opposite direction of the optimal action.

Our neurobiological model proposes that the combination of heightened responsiveness to rewards and immaturity in behavioral control areas may bias adolescents to seek immediate rather than long-term gains, perhaps explaining their increase in risky decision making and emotional reactivity. Tracking subcortical (e.g., accumbens and amygdala) and cortical (e.g., prefrontal) development of decision making and emotional reactivity across childhood and through adulthood provides additional clarification on whether changes reported in adolescence are specific to this period of development or, rather, reflect maturation that is steadily occurring in a somewhat linear pattern from childhood to adulthood.

Two recent fMRI studies spanning from childhood to adulthood provide empirical evidence consistent with our neurobiological model. In the first study (Galvan et al. 2006), we examined behavioral and neural responses to reward manipulations across development, focusing on brain regions implicated in reward-related learning and behavior in animal (Hikosaka & Watanabe 2000; Pecina et al. 2003; Schultz 2006) and adult imaging studies (e.g., Knutson et al. 2001; O'Doherty et al. 2001; Zald et al. 2004) and in studies of addiction (Hyman & Malenka 2001; Volkow & Li 2004). Based on rodent models (Laviola et al. 1999; Spear 2000) and previous imaging work (Ernst et al. 2005), we hypothesized that relative to children and adults, adolescents would show exaggerated responses to reward as indexed by elevated accumbens activity in concert with less mature recruitment of top-down prefrontal control regions.

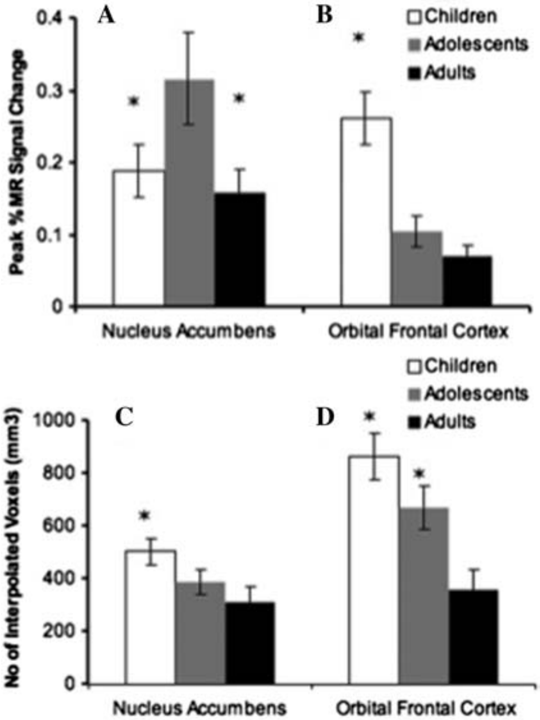

FIGURE 4. Magnitude and extent of accumbens and OFC activity to reward. Adolescents (13–17 years) showed greater percent signal change to large rewards than either children (aged 7–11 years) or adults (23–29 years) in the accumbens **(A)**. Children had the greatest percent signal change in the OFC compared to adolescents and adults **(B)**. Children had the greatest volume of activity in the accumbens relative to adolescents and adults **(C)** Children and adolescents showed greater volume of activity in the OFC than adults **(D)**. Adapted from Galvan et al. (2006).

Our findings were consistent with rodent models (Laviola et al. 2003) and previous imaging studies during adolescence (Ernst et al. 2005), which show enhanced accumbens activity to rewards. Adolescents, as compared to children and adults, showed an exaggerated accumbens response in anticipation of reward. However, both children and adolescents showed a less mature response in prefrontal control regions than adults. These findings suggest that there are different developmental trajectories for these regions. The enhancement in accumbens activity during adolescence may relate to the increase in impulsive and risky behaviors observed during this period of development (see FIG. 4).

In the second study, we examined the development of behavioral and neural responses in performance of an emotional go/no-go paradigm (Hare & Casey, in press; Hare et al. 2005). During the experiment, participants were presented with two emotional facial expressions (fearful, neutral, or happy) and were asked to respond to one of the emotions (e.g., fear) and suppress their response to the other emotion (e.g., neutral). In the context of negative emotional information (fearful faces), reaction times improved with age but were longer when detecting fearful faces relative to a neutral or happy face. This slowing in reaction time was correlated with greater amygdala activity (Hare & Casey, in press). Activity in the orbital frontal cortex increased with age, and greater orbital frontal activity relative to amygdala was associated with more efficiency in suppressing emotional reactivity (longer reaction times and greater amygdala activity). These findings are in accordance with animal studies (Baxter et al. 2000) which show connectivity between the

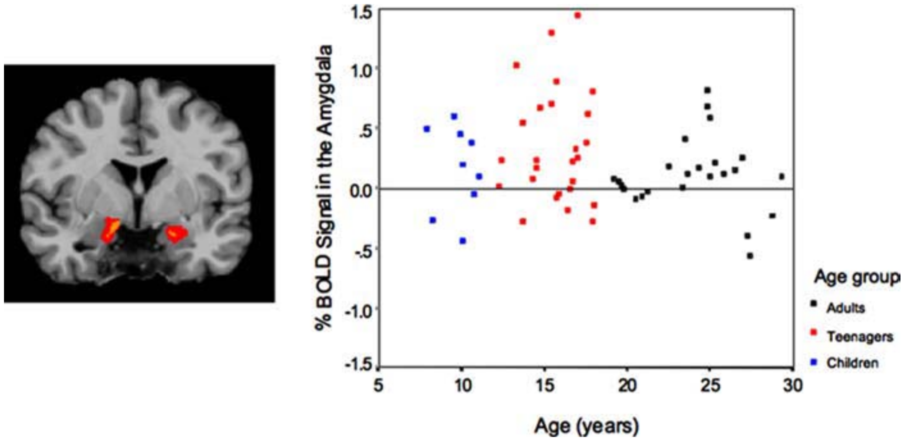

FIGURE 5. Bilateral amygdala activation (left). Graph depicts amygdala activity in adults, teenagers, and children. Adapted from Hare et al. (in press).

amygdala and orbital frontal cortex are important for assessing changes in emotional value of an object and adapting behavior accordingly.

Differential recruitment of prefrontal and subcortical regions has been reported across a number of developmental fMRI studies (Casey et al. 2002; Monk et al. 2003; Thomas et al. 2004). These findings were typically interpreted in terms of immature prefrontal regions rather than as an imbalance between prefrontal and subcortical regional development. Given evidence of prefrontal regions in guiding appropriate actions in different contexts (Miller & Cohen 2001), immature prefrontal activity might hinder appropriate estimation of future outcomes, especially when making a decision within an emotional context (i.e., heat of the moment). This interpretation is consistent with previous research showing elevated subcortical, relative to cortical, activity when decisions are biased by immediate versus long-term gains (McClure et al. 2004). Further, fMRI studies have shown limbic subcortical activity positively correlates with suboptimal choice behaviors (Kuhnen & Knutson 2005).

In sum, during adolescence, relative to childhood or adulthood, an immature ventral prefrontal cortex may not provide sufficient top-down control of robustly activated reward and affect processing regions (e.g., accumbens and amygdala). This imbalance in development of these regions and relative top-down control results in less influence of prefrontal systems (orbitofrontal cortex) relative to the accumbens and amygdala in reward valuation and emotional reactivity.

Why Would the Adolescent Brain Be Programmed This Way?

Adolescence can be described as a progressive transition from childhood into adulthood with an indefinable ontogenetic time course (Spear 2000) yet often co-occurring with puberty, which is defined by specific biological markers. The significant neuroendocrinological changes associated with puberty, such as increases in adrenal and gonadal hormones, are correlated with the development of secondary sexual characteristics and can influence brain function (for a review see Spear 2000). The onset and hormone fluctuations of puberty may provide an explanation for the observed functional differences in subcortical activity between children and adolescents, versus activity in the prefrontal region, which reflects a linear change with age.

From an evolutionary perspective, adolescence is the period in which independence skills are acquired in order to increase the success of separating from the protective influence of the family. It is also a period when there is an increase in the likelihood of harm such as injury, depression, anxiety, drug use, and addiction (Kelley et al. 2004). However, our neurobiological model suggests that risky behavior and emotional reactivity are the products of a biologically driven imbalance between increased novelty and positive sensation seeking in conjunction with immature "self-regulatory competence" (Steinberg 2004).

As previously mentioned, during adolescence, independence-seeking behaviors are prevalent across species, such as increases in peer-directed social interactions and intensifications in novelty seeking and risk-taking behaviors. In other species such as rodents, nonhuman primates, and birds, behaviors like seeking out same-age peers and fighting with parents are also observed and may be important adaptive skills to remove the adolescent from the home territory in order to mate (Spear 2000). Relative to adults, periadolescent rats show increased novelty-seeking behaviors in a free-choice novelty paradigm (Laviola et al. 1999). Neurochemical evidence indicates that the balance in the adolescent brain between cortical and subcortical dopamine systems begins to shift toward greater cortical dopamine levels during adolescence (Spear 2000). And as previously described, in the nonhuman primate there is an increase in dopamine enervation of the prefrontal cortex into early adulthood (Rosenberg & Lewis 1995). Thus this elevated risk-taking behavior appears to occur across species and have important adaptive functions.

It is possible that this developmental pattern is an evolutionary feature. One needs to engage in high-risk behavior in order to leave the family and village to find a mate. This risk behavior occurs simultaneously with an increase in sexual hormones, resulting in adolescents seeking sexual partners and is seen in other species. In conjunction with this novelty-seeking behavior, there would need to be some mechanism for detecting cues of safety or danger. The increase in emotional reactivity during this period may allow adolescents to be more vigilant and aware of threat, to ensure their survival as they move from a safe environment to a novel one. In today's society when adolescence may extend indefinitely—with individuals well into their 20s living with their parents, remaining financially dependent, and choosing mates later in life—these behaviors may be deemed inappropriate.

Biological Predispositions, Development, and Risky Behavior

The recognition of individual differences in impulse control and taking risks is not new in the field of psychology (Benthin et al. 1993). Perhaps one of the classic examples of individual differences in the social, cognitive, and developmental psychology literatures is delay of gratification (Mischel et al. 1989). Delay of gratification is typically assessed in 3- to 4-year-old toddlers. A toddler is seated in a room with two cookies and a bell. The child is then told that the experimenter will leave the room in order to prepare for upcoming activities and explains to the child that if she remains in her seat and does not eat a cookie, she will receive the large reward (2 cookies). If the child cannot wait, she should ring a bell to summon the experimenter and thereby receive the smaller reward (1 cookie). Distractions in the room are minimized, with no toys, books, or pictures. The experimenter returns after 15 minutes or after the child has rung the bell, eaten the rewards, or shown any signs of distress. Mischel (1989) showed that children typically behave in one of two ways: 1) either they ring the bell almost immediately in order to have the cookie, which means they only get one; or 2) they wait and optimize their gains to receive both cookies. This observation suggests that some individuals are better than others in their ability to control impulses in the presence of highly salient incentives, and this bias can be detected in early childhood (Mischel et al. 1989). This differential in impulse control appears to remain throughout adolescence and young adulthood (Eigsti et al. 2006).

What might explain individual differences in decision making and behavior? Some theorists have postulated that the dopaminergic mesolimbic circuitry, implicated in reward processing, underlies risky behavior (Blum et al. 2000), and that individual differences in this circuitry might relate to the propensity to engage in risky behavior (O'Doherty 2004). A number of studies have shown increases in activity in the nucleus accumbens immediately prior to making risky choices on monetary-risk paradigms (Kuhnen & Knutson 2005; Matthews et al. 2004; Montague & Berns 2002), and as described previously, adolescents show exaggerated accumbens activity to rewarding outcomes relative to children or adults (Ernst et al. 2005; Galvan et al. 2006). Collectively, these data suggest that as a group adolescents may be more likely to engage in risky choices (Gardener & Steinberg 2005). However, some adolescents will be more prone than others to engage in risky behaviors, putting them at potentially greater risk for negative outcomes. Therefore it is important to consider individual variability when examining complex brain–behavior relationships related to risk taking and reward processing in developmental populations.

To explore individual differences in risk-taking behavior, Galvan and colleagues (2007) recently examined the association between activity in reward-related neural circuitry in anticipation of a large monetary reward with behavioral measures of risk taking and impulsivity in adolescence. Specifically, Galvan and colleagues used functional magnetic resonance imaging and anonymous self-report rating scales of risky behavior, risk perception, and impulsivity in individuals between the ages of 7 and 29 years (see FIG. 6). There was a positive association between accumbens

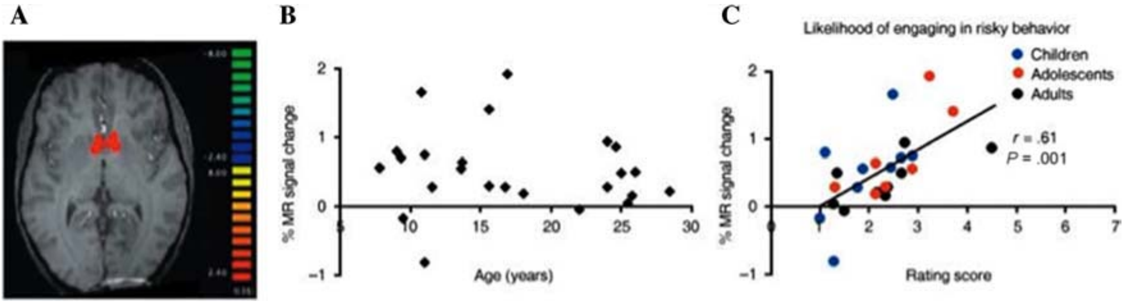

FIGURE 6. Activity in the nucleus accumbens in anticipation of reward **(A)**. Percent change in fMRI signal in the accumbens in anticipation of reward as a function of age **(B)**. The association between accumbens activity to reward and the likelihood of engaging in risky behavior in three age groups **(C)** (Adapted from Galvan et al. 2007).

activity and the likelihood of engaging in risky behavior across development. In other words, those individuals, who perceived risky behaviors as leading to dire consequences, activated the accumbens less to reward. Impulsivity ratings were not associated with accumbens activity, but rather with age, further dissociating impulse control from incentive-based risky behaviors. These findings suggest that during adolescence, some individuals have a predisposition to engage in risky behaviors due to developmental neural changes.

Adolescent behavior is repeatedly characterized as impulsive and risky, yet this review of the imaging literature suggests different neurobiological substrates and developmental trajectories for these two types of behavior. Specifically, impulsivity is associated with immature ventral prefrontal development and gradually diminishes from childhood to adulthood (Casey et al. 2005). The negative correlation between impulsivity ratings and age in the study by Galvan and colleagues (2007) further supports this notion. In contrast, risk taking is associated with an increase in accumbens activity (Kuhnen & Knutson 2005; Matthews et al. 2004; Montague & Berns 2002) that is exaggerated in adolescents, relative to both children and adults (Ernst et al. 2005; Galvan et al. 2006). Thus adolescent choices and behavior cannot be explained by impulsivity or protracted development of the prefrontal cortex alone, as children would then be predicted to be greater risk takers. The findings provide a neural basis for why some adolescents are at greater risk than others, but also demonstrate a basis for why adolescent risk-taking behavior in general is different from risk taking in children and adults.

Adolescence, Individual Differences, and Affective Disorders

Adolescence is a time of greater emotional reactivity and a period when symptoms of many psychiatric disorders (e.g., schizophrenia, depression, anxiety) manifest. Normal adolescent development can be interpreted as the coordination of emotions and behavior in the social and intellectual environment, and the development of psychopathology during adolescence can be seen as resulting from a difficulty in balancing these factors (Steinberg 2005). We have previously described enhanced bottom-up emotional processing in subcortical regions relative to less effective top-down modulation in prefrontal regions to affective information during adolescence. It is possible that this imbalance may play a role in the increased risk for affective disorders during adolescence (Steinberg 2005). Clearly, not all adolescents develop psychopathology; there must be individual variability in emotional reactivity and the ability to modulate these behaviors. Individual differences may predispose a person to be at greater risk for poorer outcomes.

The amygdala has been implicated as a key neural region in emotional dysregulation in psychiatric disorders. This region is essential to learning the emotional significance of cues in the environment (see Maren & Quirk 2004 for review). In animal studies, amygdala lesions result in a reduction of fear behavior (Anglada-Figueroa & Quirk 2005; Davis & Whalen 2001; Kalin et al. 2004), and human neuroimaging studies have shown increases in activity in the amygdala to fearful stimuli in adults (Breiter et al. 1996; Morris et al. 1998) and in children (Thomas et al. 2001b). There is evidence for dysregulation of amygdala activity in anxious and depressed children (Thomas et al. 2001a) and adults (Leppanen 2006; Rauch et al. 2003; Thomas et al. 2001a).

In a recent study, we examined individual differences in anxiety levels as measured by the Spielberger State Trait Anxiety Index and neural responses to affective information in adolescents and adults during an emotional go/no-go task (Hare et al. in press). Adolescents showed greater initial amygdala activity than

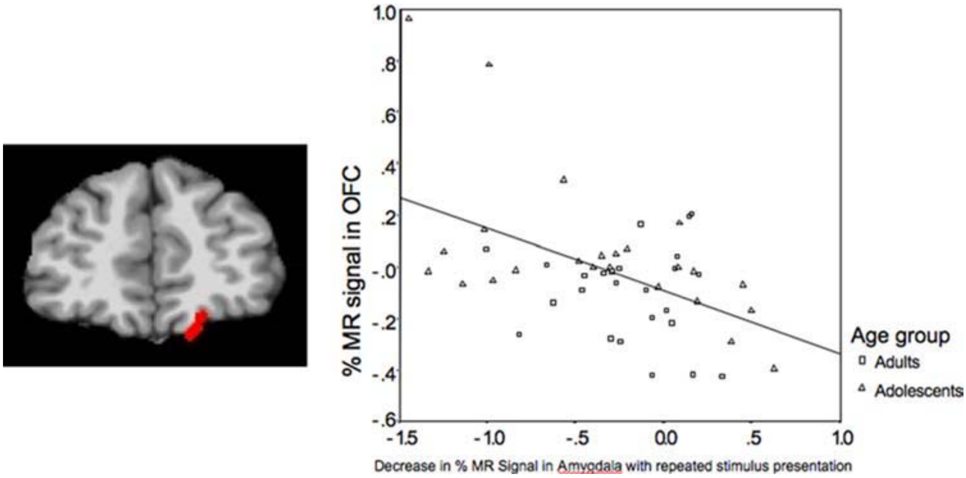

FIGURE 7. Picture depicts left orbitofrontal activity. Graph illustrates correlation of activity in the OFC and in the amygdala in both adults and adolescents (adapted from Hare et al. in press).

adults, and sustained amygdala activity was correlated with trait anxiety. Increased activity in orbitofrontal regions correlated with a decrease in amygdala activity over time (i.e., repeated presentation of a fearful face, see FIG. 7), suggesting dampening of emotional reactivity due to top-down control from prefrontal regions. These findings are consistent with animal studies showing the importance of the orbitofrontal cortex (OFC) in extinction of fear conditioning in animals with repeated exposure to empty threat (Gallagher et al. 1999) .

Our results are consistent with previous fMRI studies in clinically anxious adults and children that have shown unregulated amygdala activity to negative emotional information and less activity in the prefrontal cortex (McClure et al. 2007; Shin et al. 2004; Thomas et al. 2001b) in adolescents at risk for anxiety disorders (Perez-Edgar et al. 2007). Together these findings suggest that prefrontal regions serve to regulate emotional reactivity and that individual differences in emotion regulation may be due to an imbalance in activity between these regions that is exacerbated during adolescence.

Conclusions

Human imaging studies show structural and functional changes in frontolimbic regions (Jernigan et al. 1991; Giedd et al. 1999; Giedd et al. 1996; Sowell et al. 1999; for review, Casey et al. 2005; Jernigan et al. 1991; Giedd et al. 1999; Giedd et al. 1996; Sowell et al. 1999) for review, (Casey et al. 2005) that seem to parallel increases in cognitive control and self-regulation (Casey et al. 1997; Luna & Sweeney 2004; Luna et al. 2001; Rubia et al. 2000; Steinberg 2004). These changes appear to show a shift in activation of prefrontal regions from diffuse to more focal recruitment over time (Brown et al. 2005; Bunge et al. 2002; Casey et al. 1997; Durston et al. 2006; Moses et al. 2002) and elevated recruitment of subcortical regions during adolescence (Casey et al. 2002; Durston et al. 2006; Luna et al. 2001). Although neuroimaging studies cannot definitively characterize the mechanism of such developmental changes, these changes in volume and structure may reflect development within, and refinement of, projections to and from these brain regions during maturation suggestive of fine tuning of the system with development.

We have discussed the importance of considering individual variability when examining complex brain–behavior relationships related to risk taking, reward processing, and emotional reactivity in developmental populations. Using an approach that looks at developmental trajectories, rather than snapshots in time, allows one to comprehensively study these behaviors during development and examine individual differences. It is not possible to fully explain the emergence of affective disorders or atypical development by simply examining one time point. Longitudinal studies across development would be the best methodology to address these issues.

Taken together, the findings synthesized here indicate that increased risk-taking behavior and greater emotional reactivity in adolescence are associated with different developmental trajectories of subcortical limbic regions relative cortical control regions. These developmental changes can be exacerbated by individual differences (e.g., genetic risk) in baseline activity of limbic systems.

This model of development reconciles a number of contradictions and myths about adolescence. First, there have been many reports that suggest that adolescent behavior is due to protracted development of prefrontal cortex. However, if this were the case, then children would engage in similar or worse behavior than adolescents. The National Center for Health Statistics on adolescent behavior and mortality shows that suboptimal choices and actions observed during adolescence represent a nonlinear change in behavior, distinct from childhood and adulthood. Adolescents, unlike children, may be in situations (e.g., driving a car) that may put them at greater risk for mortality, but even when taking these conditions into account, there is still a significant elevation of risky behavior in adolescents in comparison to children. Furthermore, experimental studies have shown that when risk is held constant, such as in the appraisal of risky vignettes, children perceive greater risk in hypothetical scenarios than do adolescents (reviewed in Furby & Beyth-Marom 1992). Our neurodevelopmental model provides an explanation for these nonlinear changes in behavior.

Reyna and Farley (2006) have reconciled the second myth by showing that adolescents are able to reason and understand risks of behaviors in which they engage and do not consider themselves invincible. Prior research has also shown that adolescents knowingly engage in risky behavior, and this is often due to influences of feelings, emotions, and peers (Gardener & Steinberg 2005; Steinberg 2004, 2005). The observation that adolescents know that they are engaging in risky behavior is not supported by the sole explanation of a less developed prefrontal cortex. In this context, our model suggests that the adolescent is capable of making rational decisions, but in emotionally charged situations the more mature limbic system will win over the prefrontal control system.

When faced with an immediate personal decision, adolescents will rely less on intellectual capabilities and more on feelings. Nevertheless, when reasoning about a hypothetical, moral dilemma, the adolescent will rely more on logical information (Steinberg 2005). In other words, when a poor decision is made in the heat of the moment, the adolescent may know better, but the salience of the emotional context biases his or her behavior in opposite direction of the optimal action. This work coincides with studies of social cognition showing that adolescents make more rational decisions about hypothetical scenarios versus real-life situations (Sobesky 1983). The environmental context and emotional significance of the decision greatly influence the adolescent (Steinberg 2005).

Our findings and model have significant implications for heated debates on public policy and the treatment of minors in our judicial system. Adolescents show adult levels of intellectual capability earlier than they show evidence of adult levels of impulse control (Reyna & Farley 2006). As such, adolescents may be capable of making informed choices about their future (e.g., terminating a pregnancy) but do not yet have full capacity to override impulses in emotionally charged situations that require decisions in the heat of the moment. Unfortunately, judges, politicians, advocates, and journalists are biased toward drawing a single line between adolescence and adulthood for different purposes under the law that is at odds with developmental cognitive neuroscience (Steinberg et al. in press). Our neurodevelopmental model of adolescence will hopefully help to make strides in moving this single line to multiple lines that consider developmental changes across both context (emotionally charged or not) and time (in the moment or in the future).

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Conflict of Interests

The authors declare no conflicts of interest.

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A social neuroscience perspective on adolescent risk-taking

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Abstract

This article proposes a framework for theory and research on risk-taking that is informed by developmental neuroscience. Two fundamental questions motivate this review. First, why does risk-taking increase between childhood and adolescence? Second, why does risk-taking decline between adolescence and adulthood? Risk-taking increases between childhood and adolescence as a result of changes around the time of puberty in the brain's socio-emotional system leading to increased reward-seeking, especially in the presence of peers, fueled mainly by a dramatic remodeling of the brain's dopaminergic system. Risk-taking declines between adolescence and adulthood because of changes in the brain's cognitive control system—changes which improve individuals' capacity for self-regulation. These changes occur across adolescence and young adulthood and are seen in structural and functional changes within the prefrontal cortex and its connections to other brain regions. The di ering timetables of these changes make mid-adolescence a time of heightened vulnerability to risky and reckless behavior.

Keywords: Adolescents; Risk-taking; Social neuroscience; Reward-seeking; Self-regulation; Prefrontal cortex; Peer influence; Decision making; Dopamine; Oxytocin; Brain development

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Introduction

Adolescent risk-taking as a public health problem

It is widely agreed among experts in the study of adolescent health and development that the greatest threats to the well-being of young people in industrialized societies come from preventable and often self-inflicted causes, including automobile and other accidents (which together account for nearly half of all fatalities among American youth), violence, drug and alcohol use, and sexual risk-taking (Blum & Nelson-Mmari, 2004; Williams, Holmbeck, & Greenley, 2002). Thus, while considerable progress has been made in the prevention and treatment of disease and chronic illness among this age group, similar gains have not been made with respect to reducing the morbidity and mortality that result from risky and reckless behavior (Hein, 1988). Although rates of certain types of adolescent risk-taking, such as driving under the influence of alcohol or having unprotected sex, have dropped, the prevalence of risky behavior among teenagers remains high, and there has been no decline in adolescents' risk behavior in several years (Centers for Disease Control & Prevention, 2006).

It is also the case that adolescents engage in more risky behavior than adults, although the magnitude of age di erences in risk-taking vary as a function of the specific risk in question and the age of the "adolescents" and "adults" used as comparison groups; rates of risk-taking are high among 18- to 21-year-olds, for instance, some of whom may be classified as adolescents and some who may be classified as adults. Nonetheless, as a general rule, adolescents and young adults are more likely than adults over 25 to binge drink, smoke cigarettes, have casual sex partners, engage in violent and other criminal behavior, and have fatal or serious automobile accidents, the majority of which are caused by risky driving or driving under the influence of alcohol. Because many forms of risk behavior initiated in adolescence elevate the risk for the behavior in adulthood (e.g., drug use), and because some forms of risk-taking by adolescents put individuals of other ages at risk (e.g., reckless driving, criminal behavior), public health experts agree that reducing the rate risk-taking by young people would make a substantial improvement in the overall well-being of the population (Steinberg, 2004).

False leads in the prevention and study of adolescent risk-taking

The primary approach to reducing adolescent risk-taking has been through educational programs, most of them school-based. There is reason to be highly skeptical about the e ectiveness of this e ort, however. According to AddHealth data (Bearman, Jones, & Udry, 1997), virtually all American adolescents have received some form of educational intervention designed to reduce smoking, drinking, drug use, and unprotected sex, but the most recent report of findings from the Youth Risk Behavior Survey, conducted by the Centers for Disease Control and Prevention, indicates that more than one-third of high school students did not use a condom either the first time or even the last time they had sexual intercourse, and that during the year prior to the survey, nearly 30% of adolescents rode in a car driven by someone who had been drinking, more than 25% reported multiple episodes of binge drinking, and nearly 25% were regular cigarette smokers (Centers for Disease Control & Prevention, 2006).

Although it is true, of course, that the situation might be even worse were it not for these educational e orts, most systematic research on health education indicates that even the best programs are far more successful at changing individuals' knowledge than in altering their behavior (Steinberg, 2004, 2007). Indeed, well over a billion dollars each year are spent educating adolescents about the dangers of smoking, drinking, drug use, unprotected sex, and reckless driving—all with surprisingly little impact. Most taxpayers would be surprised—perhaps shocked—to learn that vast expenditures of public dollars are invested in health, sex, and driver education programs that either do not work, such as D.A.R.E. (Ennett, Tobler, Ringwalt, & Flewelling, 1994), abstinence education (Trenholm et al., 2007), or driver training (National Research Council, 2007), or are at best of unproven or unstudied e ectiveness (Steinberg, 2007).

The high rate of risky behavior among adolescents relative to adults, despite massive, ongoing, and costly e orts to educate teenagers about its potentially harmful consequences, has been the focus of much theorizing and empirical research by developmental scientists for at least 25 years. Most of this work has been informative, but in an unexpected way. In general, where investigators have looked to find di erences between adolescents and adults that would explain the more frequent risky behavior of youth, they have come up empty handed. Among the widely-held beliefs about adolescent risk-taking that have not been supported empirically are (a) that adolescents are irrational or deficient in their information processing, or that they reason about risk in fundamentally di erent ways than adults; (b) that adolescents do not perceive risks where adults do, or are more likely to believe that they are invulnerable; and (c) that adolescents are less risk-averse than adults. None of these assertions is correct: The logical reasoning and basic information-processing abilities of 16-year-olds are comparable to those of adults; adolescents are no worse than adults at perceiving risk or estimating their vulnerability to it (and, like adults, overestimate the dangerousness associated with various risky behaviors); and increasing the salience of the risks associated with making a poor or potentially dangerous decision has comparable e ects on adolescents and adults (Millstein & Halpern-Felsher, 2002; Reyna & Farley, 2006; Steinberg & Cau man, 1996; see also Rivers, Reyna, & Mills, 2008, this issue). Indeed, most studies find few, if any, age di erences in individuals' evaluations of the risks inherent in a wide range of dangerous behaviors (e.g., driving while drunk, having unprotected sex), in their judgments about the seriousness of the consequences that might result from risky behavior, or in the ways that they evaluate the relative costs and benefits of these activities (Beyth-Marom, Austin, Fischo , Palmgren, & Jacobs-Quadrel, 1993). In sum, adolescents' greater involvement than adults in risk-taking does not stem from ignorance, irrationality, delusions of invulnerability, or faulty calculations (Reyna & Farley, 2006).

The fact that adolescents are knowledgeable, logical, reality-based, and accurate in the ways in which they think about risky activity—or, at least, as knowledgeable, logical, reality-based, and accurate as their elders—but engage in higher rates of risky behavior than adults raises important considerations for both scientists and practitioners. For the former, this observation pushes us to think di erently about the factors that may contribute to age di erences in risky behavior and to ask what it is that changes between adolescence and adulthood that might account for these di erences. For the latter, it helps explain why educational interventions have been so limited in their success, suggests that providing adolescents with information and decision-making skills may be a misguided strategy, and argues that we need a new approach to public health interventions aimed at reducing adolescent risk-taking if it is adolescents' actual behavior that we wish to change.

These sets of scientific and practical considerations form the basis for this article. In it, I argue that the factors that lead adolescents to engage in risky activity are social and emotional, not cognitive; that the field's emerging understanding of brain development in adolescence suggests that immaturity in these realms may have a strong maturational and perhaps unalterable basis; and that efforts to prevent or minimize adolescent risk-taking should therefore focus on changing the context in which risky activity takes place rather than mainly attempting, as current practice does, to change what adolescents know and the ways they think.

A social neuroscience perspective on adolescent risk-taking

Advances in the developmental neuroscience of adolescence

The last decade has been one of enormous and sustained interest in patterns of brain development during adolescence and young adulthood. Enabled by the growing accessibility and declining cost of structural and functional Magnetic Resonance Imaging (MRI) and other imaging techniques, such as Diffusion Tensor Imaging (DTI), an expanding network of scientists have begun to map out the course of changes in brain structure between childhood and adulthood, describe age differences in brain activity during this period of development, and, to a more modest degree, link findings on the changing morphology and functioning of the brain to age differences in behavior. Although it is wise to heed the cautions of those who have raised concerns about "brain overclaim" (Morse, 2006), there is no doubt that our understanding of the neural underpinnings of adolescent psychological development is shaping—and reshaping—the ways in which developmental scientists think about normative (Steinberg, 2005) and atypical (Steinberg et al., 2006) development in adolescence.

It is important to point out that our knowledge of changes in brain structure and function during adolescence far exceeds our understanding of the actual links between these neurobiological changes and adolescent behavior, and that much of what is written about the neural underpinnings of adolescent behavior—including a fair amount of this article—is what we might characterize as "reasonable speculation." Frequently, contemporaneous processes of adolescent neural and behavioral development—for example, the synaptic pruning that occurs in the prefrontal cortex during adolescence and improvements in long-term planning—are presented as causally linked without hard data that even correlates these developments, much less demonstrates that the former (brain) influences the latter (behavior), rather than the reverse. It is therefore wise to be cautious about simple accounts of adolescent emotion, cognition, and behavior that attribute changes in these phenomena directly to changes in brain structure or function. Readers of a certain age are reminded of the many premature claims that characterized the study of hormone–behavior relationships in adolescence that appeared in the developmental literature in the mid-1980s soon after techniques for performing salivary assays became widespread and relatively inexpensive, much as brain imaging techniques have in the last decade. Alas, the search for direct hormone–behavior linkages proved more difficult and less fertile than many scientists had hoped (Buchanan, Eccles, & Becker, 1992), and there are few effects of hormones on adolescent behavior that are not conditioned on the environment in which the behavior occurs; even something as hormonally driven as libido only affects sexual behavior in the right context (Smith, Udry, & Morris, 1985). There is no reason to expect that brain–behavior relationships will be any less complicated. There is, after all, a long history of failed attempts to explain everything adolescent as biologically determined dating back not only to Hall (1904), but to early philosophical treatises on the period (Lerner & Steinberg, 2004). These caveats notwithstanding, the current state of our knowledge about adolescent brain development (both structural and functional) and possible brain–behavior links during this period, although incomplete, is nonetheless sufficient to offer some insight into ''emerging directions'' in the study of adolescent risk-taking.

The aim of this article is to provide a review of the most important discoveries in our understanding of adolescent brain development relevant to the study of adolescent risk-taking and to sketch out a rudimentary framework for theory and research on risk-taking that is informed by developmental neuroscience. Before proceeding, a few words about this point of view are in order. Any behavioral phenomenon can be studied at multiple levels. The development of risk-taking in adolescence, for example, can be approached from a psychological perspective (focusing on increases in emotional reactivity that may underlie risky decision-making), a contextual perspective (focusing on interpersonal processes that influence risky behavior), or a biological perspective (focusing on the endocrinology, neurobiology, or genetics of sensation-seeking). All of these levels of analysis are potentially informative, and most scholars of adolescent psychopathology agree that the study of psychological disorder has profited from cross-fertilization among these various approaches (Cicchetti & Dawson, 2002).

My emphasis on the neurobiology of adolescent risk-taking in this review is not intended to downplay the importance of studying the psychological or contextual aspects of the phenomenon, any more than studying changes in neuroendocrine functioning in adolescence that might increase vulnerability to depression (e.g., Walker, Sabuwalla, & Huot, 2004) would obviate the need to study the psychological or contextual contributors to, manifestations of, or treatment of the illness. Nor does my focus on the neurobiology of adolescent risk-taking reflect a belief in the primacy of biological explanation over other forms of explanation, or a subscription to a naïve form of biological reductionism. At some level, of course, every aspect of adolescent behavior has a biological basis; what matters is whether understanding the biological basis helps us understand the psychological phenomenon. My point, though, is that any psychological theory of adolescent risk-taking needs to be consistent with what we know about neurobiological functioning during this time period (just as any neurobiological theory ought to be consistent with what we know about psychological functioning), and that most extant psychological theories of adolescent risk-taking, in my view, do not map well onto what we know about adolescent brain development. To the extent that these theories are inconsistent with what we know about brain development they are likely to be wrong, and so long as they continue to inform the design of preventive interventions, these interventions unlikely to be effective.

A tale of two brain systems

Two fundamental questions about the development of risk-taking in adolescence motivate this review. First, why does risk-taking increase between childhood and adolescence? Second, why does risk-taking decline between adolescence and adulthood? I believe that developmental neuroscience provides clues that may lead us toward an answer to both questions.

In brief, risk-taking increases between childhood and adolescence as a result of changes around the time of puberty in what I refer to as the brain's socio-emotional system that lead to increased reward-seeking, especially in the presence of peers. Risk-taking declines between adolescence and adulthood because of changes in what I refer to as the brain's cognitive control system—changes which improve individuals' capacity for self-regulation, which occur gradually and over the course of adolescence and young adulthood. The differing timetables of these changes—the increase in reward-seeking, which occurs early and is relatively abrupt, and the increase in self-regulatory competence, which occurs gradually and is not complete until the mid-20s, makes mid-adolescence a time of heightened vulnerability to risky and reckless behavior.

Why does risk-taking increase between childhood and adolescence?

In my view, the increase in risk-taking between childhood and adolescence is due primarily to increases in sensation seeking that are linked to changes in patterns of dopaminergic activity around the time of puberty. Interestingly, however, as I shall explain, although this increase in sensation-seeking is coincident with puberty, it is not entirely caused by the increase in gonadal hormones that takes place at this time, as is widely assumed. Nonetheless, there is some evidence that the increase in sensation-seeking that takes place in adolescence is correlated more with pubertal maturation than with chronological age (Martin et al., 2002), which argues against accounts of adolescent risk-taking that are solely cognitive, given that there is no evidence linking changes in thinking in adolescence to pubertal maturation.

Remodeling of the dopaminergic system at puberty

Important developmental changes in the dopaminergic system take place at puberty (Chambers, Taylor, & Potenza, 2003; Spear, 2000). Given the critical role of dopaminergic activity in affective and motivational regulation, these changes likely shape the course of socioemotional development in adolescence, because the processing of social and emotional information relies on the networks underlying coding for affective and motivational processes. Key nodes of these networks comprise the amygdala, nucleus accumbens, orbitofrontal cortex, medial prefrontal cortex, and superior temporal sulcus (Nelson, Leibenluft, McClure, & Pine, 2005). These regions have been implicated in diverse aspects of social information processing, including the recognition of socially relevant stimuli (e.g. faces, Hoffman & Haxby, 2000; biological motion, Heberlein, Adolphs, Tranel, & Damasio, 2004), social judgments (appraisal of others, Ochsner, Bunge, Gross, & Gabrieli, 2002; judging attractiveness, Aharon et al., 2001; evaluating race, Phelps et al., 2000; assessing others' intentions, Baron-Cohen, Tager-Flusberg, & Cohen, 1999; Gallagher, 2000), social reasoning (Rilling et al., 2002), and many other aspects of social information processing (for a review, see Adolphs, 2003). Importantly, among adolescents the regions that are activated during exposure to social stimuli overlap considerably with regions also shown to be sensitive to variations in reward magnitude, such as the ventral striatum and medial prefrontal areas (cf. Galvan et al., 2005; Knutson, Westdorp, Kaiser, & Hommer, 2000; May et al., 2004). Indeed, a recent study of adolescents engaged in a task in which peer acceptance and rejection were experimentally manipulated (Nelson et al., 2007) revealed greater activation when subjects were exposed to peer acceptance, relative to rejection, within brain regions implicated in reward salience (i.e., the ventral tegmental area, extended amygdala, and ventral pallidum). Because these same regions have been implicated in many studies of reward-related affect (cf., Berridge, 2003; Ikemoto & Wise, 2004; Waraczynski, 2006), these findings suggest that, at least in adolescence, social acceptance by peers may be processed in ways similar to other sorts of rewards, including non-social rewards (Nelson et al., 2007). As I explain later, this overlap between the neural circuits that mediate social information processing and reward processing helps to explain why so much adolescent risk-taking occurs in the context of the peer group.

The remodeling of the dopaminergic system within the socio-emotional network involves an initial post-natal rise and then, starting at around 9 or 10 years of age, a subsequent reduction of dopamine receptor density in the striatum and prefrontal cortex, a transformation that is much more pronounced among males than females (at least in rodents) (Sisk & Foster, 2004; Sisk & Zehr, 2005; Teicher, Andersen, & Hostetter, 1995). Importantly, however, the extent and timing of increases and decreases in dopamine receptors differ between these cortical and subcortical regions; there is some speculation that it is changes in the relative density of dopamine receptors in these two areas that underlies changes in reward processing in adolescence. As a result of this remodeling, dopaminergic activity in the prefrontal cortex increases significantly in early adolescence and is higher during this period than before or after. Because dopamine plays a critical role in the brain's reward circuitry, the increase, reduction, and redistribution of dopamine receptor concentration around puberty, especially in projections from the limbic system to the prefrontal area, may have important implications for sensation-seeking.

Several hypotheses concerning the implications of these changes in neural activity have been offered. One hypothesis is that the temporary imbalance of dopamine receptors in the prefrontal cortex relative to the striatum creates a ''reward deficiency syndrome,'' producing behavior among young adolescents that is not unlike that seen among individuals with certain types of functional dopamine deficits. Individuals with this syndrome have been postulated to ''actively seek out not only addicting drugs but also environmental novelty and sensation as a type of behavioral remediation of reward deficiency'' (Gardner, 1999, cited in Spear, 2002, p. 82). If a similar process takes place at puberty, we would expect to see increases in reward salience (the degree to which adolescents are attentive to rewards and sensitive to variations in rewards) and in reward-seeking (the extent to which they pursue rewards). As Spear writes:

> [A]dolescents may generally attain less positive impact from stimuli with moderate to low incentive value, and may pursue new appetitive reinforcers through increases in risk taking/novelty seeking and via engaging in deviant behaviors such as drug taking. The suggestion is thus that adolescents display a mini-'reward deficiency syndrome' which is similar, albeit typically transient and of lesser intensity, to that hypothesized to be associated in adults with [dopamine] hypofunctioning in reward circuitry. ... Indeed, adolescents appear to show some signs of attaining less appetitive value from a variety of stimuli relative to individuals at other ages, perhaps leading them to seek additional appetitive reinforcers via pursuit of new social interactions and engagement in risk taking or novelty seeking behaviors. Such adolescent-typical features may have been adaptive evolutionarily in helping adolescents

> to disperse from the natal unit and to negotiate with success the developmental transition from dependence to independence. In the human adolescent, these propensities may be expressed, however, in alcohol and drug use, as well as a variety of other problem behaviors (2000, pp. 446–447).

The notion that adolescents suffer from a ‘‘reward deficiency syndrome,’’ although intuitively appealing, is undermined by several studies that indicate elevated activity in subcortical regions, especially the accumbens, in response to reward during adolescence (Ernst et al., 2005; Galvan et al., 2006). An alternative account is that the increase in sensation-seeking in adolescence is due not to functional dopamine deficits but to a temporary loss of ‘‘buffering capacity’’ associated with the disappearance of dopamine autoreceptors in the prefrontal cortex that serve a regulatory negative-feedback function during childhood (Dumont, Andersen, Thompson, & Teicher, 2004, cited in Ernst and Spear, in press). This loss of buffering capacity, resulting in diminished inhibitory control of dopamine release, would result in relatively higher levels of circulating dopamine in prefrontal regions in response to comparable degrees of reward during adolescence than would be the case during childhood or adulthood. Thus, the increase in sensation-seeking seen during adolescence would not be the result, as has been speculated, of a decline in the ‘‘rewardingness’’ of rewarding stimuli that drives individuals to seek higher and higher levels of reward (as would be predicted if adolescents were especially likely to suffer from a ‘‘reward deficiency syndrome’’), but to an increase in the sensitivity and efficiency of the dopaminergic system, which, in theory, would make potentially rewarding stimuli experienced as more rewarding and thereby heighten reward salience. This account is consistent with the observation of increased dopaminergic innervation in the prefrontal cortex during adolescence (Rosenberg & Lewis, 1995), despite a reduction in dopamine receptor density.

Steroid-independent and steroid-dependent processes

I noted earlier that it is common to attribute this dopaminergic-mediated change in reward salience and reward-seeking to the impact of pubertal hormones on the brain, an attribution that I myself made in earlier writings on the subject (e.g., Steinberg, 2004). Although this remodeling is coincident with puberty, however, it is not clear that it is directly caused by it. Animals that have had their gonads removed prepubertally (and thus do not experience the increase in sex hormones associated with pubertal maturation) show the same patterns of dopamine receptor proliferation and pruning as animals who have not been gonadectomized (Andersen, Thompson, Krenzel, & Teicher, 2002). Thus it is important to distinguish between puberty (the process that leads to reproductive maturation) and adolescence (the behavioral, cognitive, and socioemotional changes of the period) which are not the same thing, either conceptually or neurobiologically. As Sisk and Foster explain, ‘‘gonadal maturation and behavioral maturation are two distinct brain-driven processes with separate timing and neurobiological mechanisms, but they are intimately coupled through iterative interactions between the nervous system and gonadal steroid hormones’’ (Sisk & Foster, 2004, p. 1040). Thus, there may well be a maturationally-driven increase in reward salience and reward seeking in early adolescence that has a strong biological basis and, that is contemporaneous with puberty, but that may only be partially related to changes in gonadal hormones in early adolescence.

In point of fact, many behavioral changes that occur at puberty (and that are sometimes mistakenly attributed to puberty) are pre-programmed by a biological clock whose timing makes them coincident with, but independent of, changes in pubertal sex hormones. Accordingly, some changes in adolescent neurobiological and behavioral functioning at puberty are steroid-independent, others are steroid-dependent, and others are the product of an interaction between the two (where steroid independent processes a ect susceptibility to steroid-dependent ones) (Sisk & Foster, 2004). Moreover, within the category of steroid-dependent changes are those that are the outcome of hormonal influences on brain organization during the pre- and perinatal periods, which set in motion changes in behavior that do not manifest themselves until puberty (referred to as organizational e ects of sex hormones); changes that are the direct result of hormonal influences at puberty (both on brain organization and on psychological and behavioral functioning, the latter of which are referred to as activational e ects); and changes that are the result of the interaction between organizational and activational influences. Even changes in sexual behavior, for example, which we normally associate with the hormonal changes of puberty, is regulated by a combination of organizational, activational, and steroid-independent processes. At this point, the extent to which changes in dopaminergic functioning at puberty are (1) steroid-independent, (2) due to the organizational e ects of exposure to sex steroids (either early in life or during adolescence, which may build on or amplify early organizational influences), (3) due to the activational influences of sex steroids at puberty, or more likely, (4) due to some mix of these factors has not been determined. It may be the case, for instance, that the structural remodeling of the dopaminergic system is not influenced by gonadal steroids at puberty but that its functioning is (Cameron, 2004; Sisk & Zehr, 2005).

There is also reason to hypothesize that sensitivity to the organizational e ects of pubertal hormones decreases with age (see Schulz & Sisk, 2006), suggesting that the impact of pubertal hormones on reward-seeking might be stronger among early maturers than on-time or late maturers. Early maturers may also be at heightened risk for risk-taking because there is a longer temporal gap between the change in the dopaminergic system and the full maturation of the cognitive control system. Given these biological di erences, we would therefore expect to see higher rates of risk-taking among early maturing adolescents than among their same-aged peers (again, arguing against a purely cognitive account of adolescent recklessness, since there are no major di erences in cognitive performance between early and late physical maturers), as well as a drop over historical time in the age of initial experimentation with risky behavior, because of the secular trend toward the earlier onset of puberty. (The average age of menarche in industrialized nations declined by about 3–4 months per decade during the first part of the 20th century and continued to drop between the 1960s and 1990s, by about 2½ months in total [see Steinberg, 2008]). There is clear evidence for both of these predictions: Early maturing boys and girls report higher rates of alcohol and drug use, delinquency, and problem behavior, a pattern seen in di erent cultures and across di erent ethnic groups within the United States (Collins & Steinberg, 2006; Deardor , Bonzales, Christopher, Roosa, & Millsap, 2005; Steinberg, 2008), and the age of experimentation with alcohol, tobacco, and illegal drugs (as well as the age of sexual debut) clearly has declined over time (Johnson & Gerstein, 1998), consistent with the historical decline in the age of pubertal onset.

Adolescent sensation-seeking and evolutionary adaptation

Although structural changes in the dopaminergic system that occur at puberty may not be directly due to the activational influences of pubertal hormones, it nevertheless makes good evolutionary sense that the emergence of some behaviors, such as sensation-seeking, occur around puberty, especially among males (among whom the dopaminergic remodeling is more pronounced, as noted earlier) (see also Spear, 2000). Sensation-seeking, because it involves ventures into uncharted waters, carries with it a certain degree of risk, but such risk-taking may be necessary in order to survive and facilitate reproduction. As Belsky and I have written elsewhere, ''The willingness to take risks, even life-threatening risks, might well have proved advantageous to our ancestors when refusing to incur such risk was in fact even more dangerous to survival or reproduction. However chancy running through a burning savannah or attempting to cross a swollen stream might have been, not doing so might have been even more risky'' (Steinberg & Belsky, 1996, p. 96). To the extent that individuals inclined to take such risks were di erentially advantaged when it came to surviving and producing descendants who would themselves survive and reproduce in future generations, natural selection would favor the preservation of inclinations toward at least some risk-taking behavior during adolescence, when sexual reproduction begins.

In addition to promoting survival in inherently risky situations, risk-taking might also confer advantages, especially upon males, by means of dominance displays and through a process called ''sexual selection'' (Diamond, 1992). With respect to the dominance displays, being willing to take risks might well have been a tactic for achieving and maintaining dominance in social hierarchies. Such means of status attainment and maintenance might have been selected for not only because they contributed to obtaining for oneself and one's kin a disproportionate share of physical resources (e.g., food, shelter, clothing), but because they also increased reproductive opportunities by preventing other males from mating. To the extent that dominance displays mediate the link between risk-taking and reproduction, it makes good evolutionary sense to delay the increase in risk-taking until pubertal maturation has taken place, so that risk-takers are more adult-like in strength and appearance.

With respect to sexual selection, displays of sensation-seeking by males may have sent messages about their desirability as a sexual partner to prospective mates. It makes biological sense for males to engage in those behaviors that attract females and for females to choose males most likely to bear o spring with high prospects of surviving and reproducing themselves (Steinberg & Belsky, 1996). In aboriginal societies that are studied by anthropologists to gain insight into the conditions under which human behavior evolved (e.g., the Ache in Venezuela; the Yamamano in Brazil; the !Kung in Africa), ''young men are constantly being assessed as prospects by those who might select them as husbands and lovers...'' (Wilson & Daly, 1993, p. 99, emphasis in original). Moreover, ''prowess in hunting, warfare, and other dangerous activity is evidently a major determinant of young men's marriageability'' (Wilson & Daly, 1993, p. 98). Readers skeptical of this evolutionary argument are reminded of the wealth of literary and cinematic allusions to the fact that adolescent girls find ''bad boys'' sexually appealing. Even in contemporary society, there is empirical evidence that adolescent girls prefer and find more attractive dominant and aggressive boys (Pellegrini & Long, 2003).

Although the notion that risk-taking is adaptive in adolescence makes more intuitive sense when applied to the analysis of male than female behavior, and although there is evidence that male adolescents engage in some forms of real-world risk-taking more frequently than females (Harris, Jenkins, & Glaser, 2006), sex di erences in risk-taking are not always seen in laboratory studies of risk-taking (e.g., Galvan, Hare, Voss, Glover, & Casey, 2007). Moreover, higher levels of risk-taking among adolescents versus adults have been reported in studies of females as well as males (Gardner & Steinberg, 2005). The fact that the gender gap in real-world risk-taking appears to be narrowing (Byrnes, Miller, & Schafer, 1999) and that imaging studies employing risk-taking paradigms do not find gender di erences (Galvan et al., 2007) suggests that sex di erences in risky behavior may mediated more by context than by biology.

Changes in sensation seeking, risk-taking, and reward sensitivity in early adolescence

Several findings from a recent study my colleagues and I have conducted on age di erences in capacities that likely a ect risk-taking are consistent with the notion that early adolescence in particular is a time of important changes in individuals' inclinations toward and risk-taking (see Steinberg, Cau man, Woolard, Graham, & Banich, submitted for publication for a description of the study). To my knowledge, this is one of the only studies of these phenomena with a sample that spans a wide enough age range (from 10 to 30 years) and is large enough ($N = 935$) to examine developmental di erences across preadolescence, adolescence, and early adulthood. Our battery included a number of widely-used self-report measures, including the Benthin Risk Perception Measure (Benthin, Slovic, & Severson, 1993), the Barratt Impulsiveness Scale (Patton, Stanford, & Barratt, 1995), and the Zuckerman Sensation-Seeking Scale (Zuckerman, Eysenck, & Eysenck, 1978),[1] as well as several new ones developed for this project, including a measure of Future Orientation (Steinberg et al., submitted for publication) and a measure of Resistance to Peer Influence (Steinberg & Monahan, 2007). The battery also included numerous computer-administered performance tasks, including the Iowa Gambling Task, which measures reward sensitivity (Bechara, Damasio, Damasio, & Anderson, 1994); a Delay Discounting task, which measures relative preference for immediate versus delayed rewards (Green, Myerson, & Ostaszewski, 1999); and the Tower of London, which measures planning ahead (Berg & Byrd, 2002).

We found a curvilinear relation between age and the extent to which individuals reported that the benefits outweighed the costs of various risky activities, such as having unprotected sex or riding in a car driven by someone who had been drinking, and between age and self-reported sensation seeking (Steinberg, Albert et al., submitted for publication). Because our version of the Iowa Gambling Task permitted us to create independent measures of respondents' selection of decks that produced monetary gains versus their avoidance of decks that produced monetary losses, we could look separately at age di erences in reward and punishment sensitivity. Interestingly, we found a curvilinear relation between age and reward sensitivity, similar to the pattern seen for risk preference and sen-

[1] Many of the items on the full Zuckerman scale appear to measure impulsivity, not sensation seeking (e.g., "I often do things on impulse.") Because we have a separate measure of impulsivity in our battery, we used only the Zuckerman items that clearly indexed thrill- or novelty-seeking (e.g., "I sometimes like to do things that are a little frightening.").

sation-seeking, but not between age and punishment sensitivity, which increased linearly (Cauffman et al., submitted for publication). More specifically, scores on sensation-seeking, risk preference, and reward sensitivity all increased from age 10 until mid-adolescence (peaking somewhere between 13 and 16, depending on the measure) and declined thereafter. Preference for short-term rewards in the Delay Discounting task was greatest among the 12- to 13-year-olds (Steinberg et al., submitted for publication), also consistent with heightened reward sensitivity around puberty. In contrast, scores on measures of other psychosocial phenomena, such as future orientation, impulse control, and resistance to peer influence, as well punishment sensitivity on the Iowa Gambling Task and planning on the Tower of London task, showed a linear increase over this same age period, suggesting that the curvilinear pattern observed with respect to sensation-seeking, risk preference, and reward sensitivity is not simply a reflection of more general psychosocial maturation. As I will explain, these two different patterns of age differences are consistent with the neurobiological model of developmental change in risk-taking I set forth in this article.

The increase in sensation-seeking, risk preference, and reward sensitivity between preadolescence and middle adolescence observed in our study is consistent with behavioral studies of rodents showing an especially significant increase in reward salience around the time of puberty (e.g., Spear, 2000). There is also evidence of a shift in the anticipation of consequences of risk-taking, with risky behavior more likely to be associated with the anticipation of negative consequences among children but with more positive consequences among adolescents, a developmental shift that is accompanied by an increase in activity in the nucleus accumbens during risk-taking tasks (Galvan et al., 2007).

Changes in neural oxytocin at puberty

The remodeling of the dopaminergic system is one of several important changes in synaptic organization that likely undergird the increase in risk-taking that takes place early in adolescence. Another important change in synaptic organization is more directly linked to the rise in gonadal hormones at puberty. In general, studies find that gonadal steroids exert a strong influence on memory for social information and on social bonding (Nelson et al., 2005), and that these influences are mediated, at least in part, through the influence of gonadal steroids on the proliferation of receptors for oxytocin (a hormone that also functions as a neurotransmitter) in various limbic structures, including the amygdala and nucleus accumbens. Although most work on changes in oxytocin receptors at puberty has examined the role of estrogen (e.g., Miller, Ozimek, Milner, & Bloom, 1989; Tribollet, Charpak, Schmidt, Dubois-Dauphin, & Dreifuss, 1989), there is also evidence of similar effects of testosterone (Chibbar, Toma, Mitchell, & Miller, 1990; Insel, Young, Witt, & Crews, 1993). Moreover, in contrast to studies of gonadectomized rodents, which indicate few effects of gonadal steroids at puberty on dopamine receptor remodeling (Andersen et al., 2002), experimental studies that manipulate gonadal steroids at puberty through post-gonadectomy administration of steroids indicate direct effects of estrogen and testosterone on oxytocin-mediated neurotransmission (Chibbar et al., 1990; Insel et al., 1993).

Oxytocin is perhaps best known for the role it plays in social bonding, especially with respect to maternal behavior, but it is also important in regulating the recognition and memory of social stimuli (Insel & Fernald, 2004; Winslow & Insel, 2004). As Nelson et al. note, "gonadal hormones have important effects on how structures within the [socio-emotional system] respond to social stimuli, and will ultimately influence the emotional and behavioral responses elicited by a social stimulus during adolescence" (2005, p. 167). These hormonal changes help explain why, relative to children and adults, adolescents show especially heightened activation of limbic, paralimbic, and medial prefrontal areas in response to emotional and social stimuli, including faces with varying emotional expressions and social feedback. They also explain why early adolescence is a time of heightened awareness of others' opinions, so much so that adolescents often engage in "imaginary audience" behavior, which involves having such a strong sense of self-consciousness that the teenager imagines that his or her behavior is the focus of everyone else's concern and attention. Feelings of self-consciousness increase during early adolescence, peak around age 15, and then decline (Ranking, Lane, Gibbons, & Gerrard, 2004). This rise and fall in self-consciousness has been attributed both to changes in hypothetical thinking (Elkind, 1967) and to fluctuations in social confidence (Ranking et al., 2004), and although these may in fact be contributors to the phenomenon, the arousal of the socio-emotional network as a result of increases in pubertal hormones probably plays a role as well.

Peer influences on risk-taking

The proposed link between the proliferation of oxytocin receptors and increased risk-taking in adolescence is not intuitively obvious; indeed, given the importance of oxytocin in maternal bonding, one might predict just the reverse (i.e., it would be disadvantageous for mothers to engage in risky behavior while caring for highly dependent o spring). My argument is not that the increase in oxytocin leads to risk-taking, however, but that it leads to an increase in the salience of peer relations, and that this increase in the salience of peers plays a role in encouraging risky behavior.

The heightened attentiveness to social stimuli that results as a consequence of puberty is particularly important in understanding adolescent risk-taking. One of the hallmarks of adolescent risk-taking is that it is far more likely than that of adults to occur in groups. The degree to which an adolescent's peers use alcohol or illicit drugs is one of the strongest, if not the single strongest, predictors of that adolescent's own substance use (Chassin et al., 2004). Research on automobile accidents indicates that the presence of same-aged passengers in a car driven by an adolescent driver significantly increases the risk of a serious accident (Simons-Morton, Lerner, & Singer, 2005). Adolescents are more likely to be sexually active when their peers are (DiBlasio & Benda, 1992; East, Felice, & Morgan, 1993; Udry, 1987) and when they believe that their friends are sexually active, whether or not their friends actually are (Babalola, 2004; Brooks-Gunn & Furstenberg, 1989; DiIorio et al., 2001; Prinstein, Meade, & Cohen, 2003). And statistics compiled by the Federal Bureau of Investigation show quite compellingly that adolescents are far more likely than adults to commit crimes in groups than by themselves (Zimring, 1998).

There are several plausible explanations for the fact that adolescent risk-taking often occurs in groups. The relatively greater prevalence of group risk-taking observed among adolescents may stem from the fact that adolescents simply spend more time in peer groups than adults do (Brown, 2004). An alternative view is that the presence of peers activates the same neural circuitry implicated in reward processing, and that this impels adolescents toward greater sensation seeking. In order to examine whether the presence of peers plays an especially important role in risk-taking during adolescence, we conducted an experiment in which adolescents (mean age 14), youths (mean age 20), and adults (mean age 34) were randomly assigned to complete a battery of computerized tasks under one of two conditions: alone or in the presence of two friends (Gardner & Steinberg, 2005). One of the tasks included in this study was a video driving game that simulates the situation in which one is approaching an intersection, sees a traffic light turn yellow, and tries to decide whether to stop or proceed through the intersection. In the task, a moving car is on the screen, and a yellow traffic light appears, signaling that at some point soon, a wall will appear and the car will crash. Loud music is playing in the background. As soon as the yellow light appears, participants must decide whether to keep driving or apply the brakes. Participants are told that the longer they drive, the more points they earn but that if the car crashes into the wall, all the points that have been accumulated are lost. The amount of time that elapses between the appearance of the light and the appearance of the wall is varied across trials, so there is no way to anticipate when the car will crash. Individuals who are more inclined to take risks in this game drive the car longer than those who are more risk averse. When subjects were alone, levels of risky driving were comparable across the three age groups. However, the presence of friends doubled risk-taking among the adolescents, increased it by fifty percent among the youths, but had no effect on the adults, a pattern that was identical among both males and females (not surprisingly, we did find a main effect for sex, with males taking more risks than females). The presence of peers also increased individuals' stated willingness to behave in an antisocial fashion significantly more among younger than older subjects, again, among both males and females.

Further evidence that the impact of peers on adolescent risk-taking may be neurally mediated by heightened activation of the socioemotional network comes from some pilot work we have conducted with two male 19-year-old subjects (Steinberg & Chein, 2006). In this work, we collected fMRI data while the subjects performed an updated version of the driving task, in which they encountered a series of intersections with traffic lights that turned yellow and had to decide whether to attempt to drive through the intersection (which would increase their reward if they made it through safely but decrease it if they crashed into an approaching car) or apply the brakes (which would decrease their reward but not as much as if they crashed the car). As in the Gardner and Steinberg (2005) study, subjects came to the lab with two friends, and we manipulated the peer context by having the peers either present in the magnet control room (viewing the subject's behavior on an external computer monitor and receiving a share of the subject's monetary incentives) or moved to an isolated room. Subjects performed two runs of the driving task in the peer-present condition, and two in the peer-absent condition; in the peer-present condition, they were told that their friends would be watching, and in the peer-absent condition, they were told that their friends would not be able to see their performance. Behavioral data collected from subjects in the scanner indicated an increase in risk-taking in the presence of peers that was similar in magnitude to that observed in the earlier study, as evidenced by an increase in the number of crashes and concomitant decrease in the frequency of braking when the traffic lights turned yellow.

Examination of the fMRI data indicated that the presence of peers activated certain regions that were not activated when the driving game was played in the peer-absent condition. As expected, regardless of peer condition, decisions in the driving task elicited a widely distributed network of brain regions including prefrontal and parietal association cortices (regions linked to cognitive control and reasoning). But in the peer-present condition, we also saw increased activity in the medial frontal cortex, left ventral striatum (primarily in the accumbens), left superior temporal sulcus, and left medial temporal structures. In other words, the presence of peers activated the socio-emotional network and led to more risky behavior. This is pilot work, of course, so it is important to be very cautious in its interpretation. But the fact that the presence of peers activated the same circuitry that is activated by exposure to reward is consistent with the notion that peers may actually make potentially rewarding—and potentially risky—activities even more rewarding. In adolescence, then, more might not only be merrier—more may also be riskier.

Summary: Arousal of the socio-emotional system at puberty

In summary, there is strong evidence that the pubertal transition is associated with a substantial increase in sensation-seeking that is likely due to changes in reward salience and reward sensitivity resulting from a biologically-driven remodeling of dopaminergic pathways in what I have called the socio-emotional brain system. This neural transformation is accompanied by a significant increase in oxytocin receptors, also within the socio-emotional system, which in turn heightens adolescents' attentiveness to, and memory for, social information. As a consequence of these changes, relative to prepubertal individuals, adolescents who have gone through puberty are more inclined to take risks in order to gain rewards, an inclination that is exacerbated by the presence of peers. This increase in reward-seeking is most apparent during the first half of the adolescent decade, has its onset around the onset of puberty, and likely peaks sometime around age 15, after which it begins to decline. Behavioral manifestations of these changes are evident in a wide range of experimental and correlational studies using a diverse array of tasks and self-report instruments, are seen across many mammalian species, and are logically linked to well-documented structural and functional changes in the brain.

This set of assertions must be tempered, however, in view of the absence of direct evidence in humans that link the biology with the behavior. As noted earlier, the fact that particular sets of neurobiological and behavioral changes occur concurrently in development can only be taken as suggestive of a connection between them. More research that simultaneously examines brain structure function and its relation to risky behavior, either in studies of age differences or in studies of individual differences, is much needed.

It also is important to emphasize that, although the increase in sensation-seeking observed in early adolescence may be maturationally driven, all individuals do not manifest this inclination in the form of dangerous, harmful, or reckless behavior. As Dahl notes, "For some adolescents, this tendency to activate strong emotions and this 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" (2004, p. 8). Presumably, many factors moderate and modulate the translation of sensation seeking into risky behavior, including maturational timing (i.e., with early maturers at greater risk), opportunities to engage in antisocial risk-taking (e.g., the degree to which adolescents' behavior is monitored by parents and other adults, the availability of alcohol and drugs, and so forth), and temperamental predispositions that may amplify or attenuate tendencies to engage in potentially dangerous activities. Individuals who are behaviorally inhibited by nature, prone to high levels of anxiety, or especially fearful would be expected to shy away from harmful activities. For example, a recent follow-up of adolescents who had been highly reactive as infants (i.e., exhibiting high motor activity and frequent crying) found them to be significantly more nervous, introverted, and morose than their counterparts who had been low-reactive (Kagan, Snidman, Kahn, & Towsley, 2007).

Why does risk-taking decline between adolescence and adulthood?

There are two plausible neurobiological processes that may help account for the decline in risky behavior that occurs between adolescence and adulthood. The first, which has received only scant attention, is that further changes in the dopaminergic system, or in reward processing that is mediated by some other neurotransmitter, take place in late adolescence that alter reward sensitivity, and, in turn, diminish reward-seeking. Little is known about changes in reward seeking after adolescence, however, and there remain inconsistencies in the literature with respect to age differences in reward sensitivity after adolescence (cf. Bjork et al., 2004; Ernst et al., 2005; Galvan et al., 2006), likely due to methodological differences between studies in the manipulation of reward salience (e.g., whether the comparison of interest is in reward versus cost or among rewards of different magnitudes) and whether the task involves the anticipation or actual receipt of the reward. Nevertheless, studies of age differences in sensation seeking (in addition to our own) show a decrease in this tendency after age 16 (Zuckerman et al., 1978), and there is some behavioral evidence (Millstein & Halpern-Felsher, 2002) suggesting that adolescents may be more sensitive than adults to variation in rewards and comparably or even less sensitive to variation in costs, a pattern borne out in our Iowa Gambling Task data (Cauffman et al., submitted for publication).

A more likely (although not mutually exclusive) cause of the decline in risky activity after adolescence concerns the development of self-regulatory capacities that occurs over the course of adolescence and during the 1920s. Considerable evidence suggests that higher level cognition, including the uniquely human capacities for abstract reasoning and deliberative action, is supported by a recently evolved brain system including the lateral prefrontal and parietal association cortices and parts of the anterior cingulate cortex to which they are highly interconnected. The maturation of this cognitive control system during adolescence is likely a primary contributor to the decline in risk-taking seen between adolescence and adulthood. This account is consistent with a growing body of work on structural and functional changes in the prefrontal cortex, which plays a substantial role in self-regulation, and in the maturation of neural connections between the prefrontal cortex and the limbic system, which permits the better coordination of emotion and cognition. These changes permit the individual to put the brakes on impulsive sensation-seeking behavior and to resist the influence of peers, which, together, should diminish risk-taking.

Structural maturation of the cognitive control system

Three important changes in brain structure during adolescence are now well-documented (see Paus, 2005, for a summary). First, there is a decrease in gray matter in prefrontal regions of the brain during adolescence, reflective of synaptic pruning, the process through which unused neuronal connections are eliminated. This elimination of unused neuronal connections occurs mainly during preadolescence and early adolescence, the period during which major improvements in basic information processing and logical reasoning are seen (Keating, 2004; Overton, 1990), consistent with the timetable for synaptic pruning in the prefrontal cortex, most of which is complete by mid-adolescence

(Casey, Tottenham, Liston, & Durston, 2005; see also Casey, Getz, & Galvan, 2008, this issue). Although some improvements in these cognitive capacities continue until age 20 or so (Kail, 1991, 1997), changes after mid-adolescence are very modest in magnitude and tend to be seen mainly in studies employing relatively demanding cognitive tasks on which performance is facilitated by greater connectivity among cortical areas, permitting more efficient processing (see below). In our study of capacities related to risk-taking described earlier, we saw no improvement in basic cognitive processes, such as working memory or verbal fluency, after age 16 (Steinberg, Cauffman et al. submitted for publication).

Second, there is an increase in white matter in these same regions, reflective of myelination, the process through which nerve fibers become sheathed in myelin, a fatty substance that provides a sort of insulation of the neural circuitry. Unlike the synaptic pruning of the prefrontal areas, which takes place early adolescence, myelination is ongoing well into the second decade of life and perhaps beyond (Lenroot et al., 2007). Improved connectivity within the prefrontal cortex should be associated with subsequent improvements in higher-order functions subserved by multiple prefrontal areas, including many aspects of executive function, such as response inhibition, planning ahead, weighing risks and rewards, and the simultaneous consideration of multiple sources of information. In contrast to our findings with respect to basic information processing, which showed no maturation beyond age 16, we found continued improvement beyond this age in self-reported future orientation (which increased through age 18) and in planning (as indexed by the amount of time subjects waited before making their first move on the Tower of London task, which increased not only through adolescence but through the early 20s).

Generally speaking, performance on tasks that activate the frontal lobes continues to improve through middle adolescence (until about age 16 on tasks of moderate difficulty), in contrast to performance on tasks that activate more posterior brain regions, which reaches adult levels by the end of preadolescence (Conklin, Luciana, Hooper, & Yarger, 2007). Improved executive function in adolescence is reflected in better performance with age on tasks known to activate the dorsolateral prefrontal cortex, such as relatively difficult tests of spatial working memory (Conklin et al., 2007) or especially challenging tests of response inhibition (Luna et al., 2001); and the ventromedial prefrontal cortex, such as the Iowa Gambling Task (Crone & van der Molen, 2004; Hooper, Luciana, Conklin, & Yarger, 2004). Although some tests of executive function simultaneously activate both the dorsolateral and ventromedial regions, there is some evidence that the maturation of these regions may take place along somewhat different timetables, with performance on exclusively ventromedial tasks reaching adult levels somewhat earlier than performance on exclusively dorsolateral tasks (Conklin et al., 2007; Hooper et al., 2004). In one recent study of age differences in cognitive performance using tasks known to differentially activate these two prefrontal regions, there was age-related improvement into middle adolescence on both types of tasks, but there were no significant correlations between performance on the ventromedial and dorsolateral tasks, suggesting that maturation of the ventromedial prefrontal cortex may be a developmentally distinct process from the maturation of the dorsolateral prefrontal cortex (Hooper et al., 2004). Performance on especially difficult tasks known to activate dorsolateral areas continues to improve during late adolescence (Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006; Luna et al., 2001).

Third, as evidenced in the proliferation of projections of white matter tracts across different brain regions, there is an increase not only in connections among cortical areas (and between different areas of the prefrontal cortex), but between cortical and subcortical areas (and, especially, between the prefrontal regions and the limbic and paralimbic areas, including the amygdala, nucleus accumbens, and hippocampus) (Eluvathingal, Hasan, Kramer, Fletcher, & Ewing-Cobbs, 2007). This third anatomical change should be associated with improved coordination of affect and cognition, and reflected in improved emotion regulation, facilitated by the increased connectivity of regions important in the processing of emotional and social information (e.g., the amygdala, ventral striatum, orbitofrontal cortex, medial prefrontal cortex, and superior temporal sulcus) and regions important in cognitive control processes (e.g., the dorsolateral prefrontal cortex, anterior and posterior cingulate, and temporo-parietal cortices). Consistent with this, we found increases in self-reported impulse control through the mid-20s (Steinberg, Albert et al., submitted for publication).

Functional changes in the cognitive control system

Functional studies of brain development in adolescence are largely consistent with the findings from structural studies and from studies of cognitive and psychosocial development. Several overarching conclusions can be drawn from this research. First, studies point to a gradual development of cognitive control mechanisms over the course of adolescence and early adulthood, consistent with the anatomical changes in the dorsolateral prefrontal cortex described earlier. Imaging studies examining performance on tasks requiring cognitive control (e.g., Stroop, flanker tasks, Go-No/Go, antisaccade) have shown that adolescents tend to recruit the network less efficiently than do adults, and that regions whose activity correlates with task performance (i.e., cognitive control areas) become more focally activated with age (Durston et al., 2006). It has been suggested that this increasingly focal engagement of cognitive control areas reflects a strengthening of connections within the control network, and of its projections to other regions (a claim consistent with data on increased connectivity among cortical areas with development; Liston et al., 2006).

Improved performance on cognitive control tasks between childhood and adulthood is accompanied by two different functional changes: Between childhood and adolescence, there appears to be an increase in activation of the dorsolateral prefrontal cortex (Adleman et al., 2002; Casey, Giedd, & Thomas, 2000; Durston et al., 2002; Luna et al., 2001; Tamm, Menon, & Reiss, 2002), consistent with the synaptic pruning and myelination of this region at this time. The period between adolescence and adulthood, in contrast, appears to be one of fine-tuning (rather than one characterized by an overall increase or decrease in activation; Brown et al., 2005), presumably facilitated by the more extensive connectivity within and across brain areas (Crone et al., 2006; Luna et al., 2001). For example, imaging studies using tasks in which individuals are asked to inhibit a ‘‘prepotent’’ response, like trying to look away from, rather than toward, a point of light (an antisaccade task), have shown that adolescents tend to recruit the cognitive control network less selectively and efficiently than do adults, perhaps overtaxing the capacity of the regions they activate (Luna et al., 2001). In essence, whereas the advantage that adolescents have over children in cognitive control inheres in the maturation of brain regions implicated in executive function (mainly, dorsolateral prefrontal cortex), the reasons the cognitive control system of adults is more effective than that of adolescents may be because adults’ brains evince more differentiated activation in response to different task demands. This would be consistent with the notion that performance on relatively basic tests of executive processing reaches adult levels around age 16, whereas performance of especially challenging tasks, which may require more efficient activation, continues to improve in late adolescence.

While the cognitive control network is clearly implicated in reasoning and decision-making, several recent findings suggest that decision-making is often governed by a competition between this network and the socio-emotional network (Drevets & Raichle, 1998). This competitive interaction has been implicated in a wide range of decision-making contexts, including drug use (Bechara, 2005; Chambers et al., 2003), social decision processing (Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003), moral judgments (Greene, Nystrom, Engell, Darley, & Cohen, 2004), and the valuation of alternative rewards and costs (Ernst et al., 2004; McClure, Laibson, Loewenstein, & Cohen, 2004), as well as in an account of adolescent risk-taking (Chambers et al., 2003). In each instance, impulsive or risky choices are presumed to arise when the socio-emotional network dominates the cognitive control network. More specifically, risk-taking is more likely when the socio-emotional network is relatively more activated or when processes mediated by the cognitive control network are disrupted. For example, McClure et al. (2004) have shown that decisions reflecting a preference for smaller immediate rewards over larger delayed rewards are associated with relatively increased activation of the ventral striatum, orbitofrontal cortex, and medial prefrontal cortex, all regions linked to the socio-emotional network, whereas regions implicated in cognitive control (dorsolateral prefrontal cortex, parietal areas) are engaged equivalently across decision conditions. Similarly, two recent studies (Ernst et al., 2004; Matthews, Simmons, Lane, & Paulus, 2004) show that increased activity in regions of the socio-emotional network (ventral striatum, medial prefrontal cortex) predicts the selection of comparatively risky (but potentially highly rewarding) choices over more conservative choices. Finally, one recent experimental study found that transient disruption of right dorsolateral prefrontal cortical function via transcranial magnetic stimulation (i.e., disruption of a region known to be crucial to cognitive control) increased risk-taking in a gambling task (Knoch et al., 2006).

Coordination of cortical and subcortical functioning

A second, but less well documented, change in brain function during adolescence involves the increasing involvement of multiple brain regions in tasks involving the processing of emotional information (e.g., facial expressions, emotionally arousing stimuli). Although it has been widely reported that adolescents show significantly greater limbic activity than adults when exposed to emotional stimuli (which is popularly interpreted as evidence for adolescents' ''emotionality''), this is not consistently the case. In some such studies adolescents do show a tendency toward relatively more limbic activation than adults (e.g., Baird et al., 1999; Killgore & Yurgelun-Todd, 2007), but in others, adolescents show relatively more prefrontal activation (e.g., Baird, Fugelsang, & Bennett, 2005; Nelson et al., 2003). Much depends on the stimuli used, whether the stimuli are presented explicitly or subliminally, and the specific instructions given to the participant (e.g., whether the participant is asked to pay attention to the emotion or to pay attention to some other aspect of the stimulus material). A more cautious reading of this literature is not that adolescents are unequivocally more prone than adults to activation of subcortical brain systems when presented with emotional stimuli (or that they are more ''emotional''), but that they may be less likely to activate multiple cortical and subcortical areas simultaneously, suggesting deficits, relative to adults, in the synchronization of cognition and a ect.

This lack of cross-talk across brain regions results not only in individuals acting on gut feelings without fully thinking (the stereotypic portrayal of adolescent risk-taking), but also in thinking too much when one's gut feelings ought to be attended to (which teenagers also do from time to time) (see also Reyna & Farley, 2006, for a discussion of adolescents' deficiencies in intuitive, or ''gist-based,'' decision-making). Few readers would be surprised to hear of studies showing more impulsivity and less deliberative thinking among adolescents than adults. But in one recent study (Baird et al., 2005), when asked whether some obviously dangerous activities (e.g., setting one's hair on fire, swimming with sharks) were ''good ideas,'' adolescents took significantly longer (i.e., deliberated more) than adults to respond to the questions and activated a less narrowly distributed set of cognitive control regions, particularly in the dorsolateral prefrontal cortex—a result reminiscent of Luna's study of age di erences in response inhibition (Luna et al., 2001). This was not the case when the queried activities were not dangerous ones, however (e.g., eating salad, taking a walk), where adolescents and adults performed similarly and showed similar patterns of brain activation. Thus, it is the lack of coordination of a ect and thinking, rather than the dominance of a ect over thinking, that may characterize adolescence. This results in two patterns of risk-taking that are behaviorally quite di erent (impulsively acting before thinking, and overthinking rather than acting impulsively) but that actually may have a similar neurobiological origin.

The temporal gap between the development of basic information-processing abilities, which is facilitated by maturation of the prefrontal cortex and largely complete by age 16, and the development of abilities that require the coordination of a ect and cognition, which is facilitated by improved connections among cortical regions and between cortical and subcortical regions, and which is a later development, is illustrated in Fig. 1. The figure is based on data from our study of 10- to 30-year-olds mentioned earlier (Steinberg, Cau man et al. submitted for publication). The two capacities graphed are basic intellectual ability, which is a composite score that combines performance on tests of working memory (Thompson-Schill, 2002), digit-span, and verbal fluency; and psychosocial maturity, which composites scores of the self-report measures of impulsivity, risk perception,

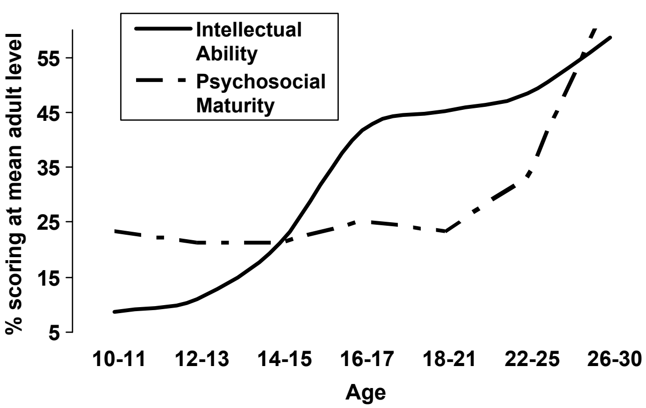

Fig. 1. Proportion of individuals in each age group scoring at or above the mean for 26- to 30- year-olds on indices of intellectual and psychosocial maturity. From Steinberg, Cau man et al. submitted for publication.

sensation-seeking, future orientation, and resistance to peer influence mentioned earlier. Mature functioning with respect to these psychosocial capacities requires the e ective coordination of emotion and cognition. The figure shows the proportion of individuals in each age group who score at or above the mean level of the 26- to 30-year-olds in our sample on the psychosocial and intellectual composites. As the figure indicates, and consistent with other studies, basic intellectual abilities reach adult levels around age 16, long before the process of psychosocial maturation is complete—well into the young adult years.

Changes in brain connectivity and the development of resistance to peer influence

The improved connectivity between cortical and subcortical areas also has implications for understanding changes in susceptibility to peer influence, which, as I noted, is an important contributor to risk behavior during adolescence. Resistance to peer influence, I believe, is achieved by cognitive control of the impulsive reward-seeking behavior that is stimulated by the presence of peers through activation of the socio-emotional network. To the extent that improved coordination between the cognitive control and socio-emotional networks facilitates this regulatory process, we should see gains in resistance to peer influence over the course of adolescence that continue at least into late adolescence (when maturation of inter-region connections are still ongoing). This is precisely what we have found in our own work, in which we show that gains in self-reported resistance to peer influence continue at least until 18 (Steinberg & Monahan, 2007), and that the actual impact of the presence of peers on risky behavior is still evident among college undergraduates averaging 20 years in age (Gardner & Steinberg, 2005).

Two recent studies of the relation between resistance to peer influence and brain structure and function provide further support for this argument. In an fMRI study of 43 10-year-olds who were exposed to emotionally-arousing video clips containing social information (clips of angry hand movements or angry facial expressions), we found that individuals with relatively lower scores on our self-report measure of resistance to peer influence showed significantly greater activation of regions implicated in the perception of others' actions (i.e., right dorsal premotor cortex), whereas those with relatively higher scores showed greater functional connectivity between these action-processing regions and regions implicated in decision-making (i.e., dorsolateral prefrontal cortex); such di erences were not observed when individuals were presented with emotionally-neutral clips (Grosbras et al., 2007). These results suggest that individuals who are especially susceptible to peer influence may be unusually aroused by signs of anger in others but less able to exert inhibitory control over their responses to such stimuli. In a second study, of di erences in brain morphology between individuals (aged 12–18) scoring high versus low in resistance to peer influence, we found morphological evidence that, after controlling for age, adolescents high in resistance to peer influence showed evidence of greater structural connectivity between premotor and prefrontal regions, a pattern consistent with the more frequent concurrent engagement of these networks among individuals more able to resist peer pressure (Paus et al., in press). Also consistent with this is work showing that recruitment of cognitive control resources (which would counter impulsive susceptibility to peer pressure) is greater among individuals with stronger connections between frontal and striatal regions (Liston et al., 2006).

Summary: improvements in cognitive control over adolescence and young adulthood

In sum, risk taking declines between adolescence and adulthood for two, and perhaps, three reasons. First, the maturation of the cognitive control system, as evidenced by structural and functional changes in the prefrontal cortex, strengthens individuals' abilities to engage in longer-term planning and inhibit impulsive behavior. Second, the maturation of connections across cortical areas and between cortical and subcortical regions facilitates the coordination of cognition and affect, which permits individuals to better modulate socially and emotionally aroused inclinations with deliberative reasoning and, conversely, to modulate excessively deliberative decision-making with social and emotional information. Finally, there may be developmental changes in patterns of neurotransmission after adolescence that change reward salience and reward-seeking, but this is a topic that requires further behavioral and neurobiological research before saying anything definitive.

Implications for prevention and intervention

In many respects, then, risk-taking during adolescence can be understood and explained as the product of an interaction between the socio-emotional and cognitive control networks (Drevets & Raichle, 1998), and adolescence is a period in which the former abruptly becomes more assertive at puberty while the latter gains strength only gradually, over a longer period of time. It is important to note, however, that the socio-emotional network is not in a state of constantly high activation, even during early and middle adolescence. Indeed, when the socio-emotional network is not highly activated (for example, when individuals are not emotionally excited or are alone), the cognitive control network is strong enough to impose regulatory control over impulsive and risky behavior, even in early adolescence; recall that in our video driving game study, when individuals were alone we found no age differences in risk-taking between adolescents who averaged 14 and adults who averaged 34 (Gardner & Steinberg, 2005). In the presence of peers or under conditions of emotional arousal, however, the socio-emotional network becomes sufficiently activated to diminish the regulatory effectiveness of the cognitive control network. (We are currently beginning research in our lab to examine whether positive or negative emotional arousal has differential effects on risk-taking during adolescence and adulthood.) During adolescence, the cognitive control network matures, so that by adulthood, even under conditions of heightened arousal in the socio-emotional network inclinations toward risk-taking can be modulated.

What does this formulation mean for the prevention of unhealthy risk-taking in adolescence? Given extant research suggesting that it is not the way that adolescents think or what they don't know or understand that is the problem, rather than attempting to change how adolescents view risky activities a more profitable strategy might focus on limiting opportunities for immature judgment to have harmful consequences. As I noted in the introduction to this article, more than 90% of all American high school students have had sex, drug, and driver education in their schools, yet large proportions of them still have unsafe sex, binge drink, smoke cigarettes, and drive recklessly (some all at the same time; Steinberg, 2004). Strategies such as raising the price of cigarettes, more vigilantly enforcing laws governing the sale of alcohol, expanding adolescents' access to mental health and contraceptive services, and raising the driving age would likely be more effective in limiting adolescent smoking, substance abuse, pregnancy, and automobile fatalities than attempts to make adolescents wiser, less impulsive, or less shortsighted. Some things just take time to develop, and mature judgment is probably one of them.

The research reviewed here suggests that heightened risk-taking during adolescence is likely to be normative, biologically driven, and, to some extent, inevitable. There is probably very little we can or ought to do to either attenuate or delay the shift in reward sensitivity that takes place at puberty, a developmental shift that likely has evolutionary origins. It may be possible to accelerate the maturation of self-regulatory competence, but no research has examined whether this can be done. We do know that individuals of the same age vary in their impulse control, planfulness, and susceptibility to peer influence, and that variations in these characteristics are related to variations in risky and antisocial behavior (Steinberg, 2008). Although there is a wealth of studies showing familial influences on psychosocial maturity in adolescence, indicating that adolescents who are raised in homes characterized by authoritative parenting (i.e., parenting that is warm but firm) are more mature and less likely to engage in risky or antisocial behavior (Steinberg, 2001), we do not know whether this link is mediated by changes in the underlying bases of self-regulation, or whether they mainly reflect the imposition of external constraints (through parental monitoring) on adolescents' access to harmful situations and substances. Nonetheless, there is reason to study whether altering the context in which adolescents develop may have beneficial effects on the development of self-regulatory capacities. Understanding how contextual factors, both inside and outside the family, influence the development of self-regulation, and the neural underpinnings of these processes, should be a high priority for those interested in the physical and psychological well being of young people.

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The Young and the Reckless: Adolescent Reckless Behavior

Jeffrey Arnett

In Rio de Janeiro in Brazil, they "surf" on the tops of trains, standing with arms outstretched as the trains rush along. The surfers—adolescents, girls as well as boys—are undeterred by the death of 150 fellow surfers per year and the injury of 400 more, from falling off trains or from hitting the 3,000-volt electric cable that runs above. On Truk Island in the South Pacific, drunkenness, fighting, and sexual experiences with a variety of lovers are all part of typical development for young men in their late teens and early 20s. They also go spearfishing where large sharks are common, and seek out other "daredevil risks with life and limb."[1] In urban New Jersey in the United States, adolescent boys steal automobiles, then drive them wildly for a few hours before crashing or abandoning them.

Why do many adolescents seek out experiences that involve physical, psychological, or legal risks? What blend of developmental and socialization factors leads to reckless behavior among adolescents? Researchers and theorists have offered a number of explanations, focusing on such behavior as driving an automobile at high speeds or while intoxicated, having sex without contraception or with someone not known well, using illegal drugs, and committing crimes. Richard Jessor, for example, has suggested that the developmental motivation for such behavior is the desire of adolescents to achieve adult status.[2] His theory also includes personality characteristics (such as self-esteem and value placed on achievement), family environment, and religiosity. Charles Irwin, Jr., presents a model that emphasizes pubertal timing and its effects on risk perception and peer-group association.[3] My own focus is on three developmental predispositions for reckless behavior in adolescence—sensation seeking, egocentrism, and aggressiveness—and their interaction with the cultural socialization environment.

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THE DEVELOPMENTAL BASIS

Sensation Seeking

One characteristic of adolescent development that contributes to reckless behavior is a heightened level of sensation seeking.[4] Sensation seeking is a propensity for seeking out novel and intense experiences, and many types of reckless behavior are experiences of this kind. Driving a car at high speeds is attractive to many adolescents by virtue of the intensity of the experience. Sexual activity involves sensations that are intense and, for adolescents, novel as well. Trying illegal drugs results in novel forms of consciousness, and "to see what it was like" is a common response given by adolescents who are asked why they have used illegal drugs. Pervasive forms of adolescent criminal behavior, such as minor theft and vandalism, carry the danger of being apprehended, but many adolescents describe this sense of danger as thrilling, intoxicating. Studies have found measures of sensation seeking to be related to a wide variety of reckless behaviors, and have found sensation seeking to be higher in adolescence than in adulthood.

Egocentrism

One of the advances in cognitive development that accompany adolescence is an advance in imaginative capacities. As Jean Piaget explained, adolescents are capable of thinking in terms of hypothetical situations in a way younger children are not. Adolescents are able to imagine their own lives in a magnified and grandiose way, and may see themselves as having a specially ordained existence. This "personal fable" (to use David Elkind's term) may exclude the possibility that their course to the future might be derailed by injury, unintended pregnancy, legal prosecution, drug addiction, or even death as a consequence of reckless behavior. These outcomes are all things adolescents may see as happening to other people, not to themselves. The sense of invulnerability conferred by the personal fable may increase some adolescents' propensity to take part in reckless behavior.

Evidence supporting this theoretical idea comes chiefly from studies indicating that adolescents have a tendency to estimate that the probability of a negative outcome resulting from engaging in reckless behavior is lower for themselves than for other people.[4] For example, adolescent drivers have a stronger tendency than older drivers to rate themselves as less likely than their peers to be involved in an accident. Criminal behavior is inversely related to the perceived risk that negative consequences would result, and the perceived risk is lower in adolescence than in adulthood. Similarly, adolescent girls who have had sex without contraception estimate the probability that pregnancy would result from such behavior as lower than do girls who have not had sex without contraception.

To some extent, these studies are simply indicative of the "optimistic bias" that investigators of decision making have found to be true of people of all ages; that is, there is a tendency for individuals to believe that unpleasant events are less likely to happen to themselves than to other people. However, as noted, studies of automobile driving and criminal behavior suggest that this tendency is stronger in adolescence than in adulthood.

Aggressiveness

Because of the way the levels of hormones related to aggression rise when puberty arrives, aggressiveness seems like an obvious place to look for an explanation of why adolescents are more reckless than children or adults. In particular, levels of testosterone, which has been repeatedly found to be related to aggression, become 18 times higher by the end of puberty than at the beginning, for boys, and twice as high for girls; testosterone levels then decline after the mid-20s. These facts help explain not only why adolescents are more reckless than children or adults, but also why boys tend to be more reckless than girls for some types of reckless behavior.

Two types of reckless behavior for which aggressiveness may be particularly important are risky automobile driving and criminal behavior. Some adolescents use automobiles as a way of expressing aggressiveness. Some adults do, too, but adolescents may be more likely to do so than adults, both because testosterone levels are higher in adolescence and because adolescents may have less impulse control than adults and less social pressure to exercise it. Studies indicate that aggressiveness is related to high-speed and risky driving among adolescents and young adults. Aggressiveness also has an obvious relation to certain kinds of criminal behavior. Adolescents (especially males) have the highest rates of automobile accidents and of a wide variety of criminal activities.

SOCIALIZATION

Although the developmental predispositions I have described may incline adolescents toward reckless behavior, the socialization environment determines whether those predispositions will be expressed, and to what extent, and in what forms. Although the biological and physical developments of puberty are similar across cultures, the extent and forms of adolescent recklessness vary greatly among cultures because of differences in socialization practices.

In comparing cultures, I make a general distinction between *broad* and *narrow* socialization.[4,5] In cultures characterized by broad socialization, there is an emphasis on promoting individuality and autonomy, with the goal of restraining individuals as little as possible to allow the fullest measure of self-expression. Under narrow socialization, in contrast, obedience and conformity are the highest values, and deviation from the expected standard of behavior is punished physically or socially. In this theory, socialization has sources that include family, peers and friends, school, neighborhood and community, the legal system, the media, and the cultural belief system.

Narrow socialization is narrow in the sense that predispositions for characteristics such as sensation seeking, egocentrism, aggressiveness, and (by extension) reckless behavior are pressed into a narrower range of expression than would be the case if the expression of these characteristics were unimpeded. In cultures characterized by broad socialization, however, a broad range of inherent predispositions in these same characteristics is likely to be expressed, because the standards for behavior are less strict and violations of the standards are less likely to be punished harshly. Not all adolescents in such a socialization environment will be reckless, but those with a relatively strong predisposition for the characteristics that promote reckless behavior will find that the expression of these predispositions is not thwarted.

Evidence for the role of socialization in adolescent reckless behavior can be found in each source of socialization.

Family

Broad socialization in the family means that parents allow their adolescents a great deal of unsupervised time and encourage them to be independent and self-sufficient. Narrow socialization in the family means that parents (and perhaps other adults in the extended family) keep a close eye on their adolescents and demand obedience and deference. The importance of family socialization in adolescents' participation in reckless behavior has been supported in studies in several countries, including the United States, Canada, and Finland. These studies indicate that parental restrictions and monitoring are related to lower rates of adolescent recklessness in areas such as sexual behavior, vandalism, and substance use.

Of course, in parents' socialization of their adolescents, not only control matters, but also love. Numerous studies indicate that control without love is ineffective in discouraging antisocial behavior among adolescents. In Japan and India, for example, parents obtain a high degree of obedience from their children and adolescents while using very little overt control.[6] The relationships between parents and adolescents typically are so close emotionally that the threat of guilt and shame before their parents is enough to deter most adolescents from participating in reckless behavior.

Peers and Friends

Socialization by peers tends to be narrow, in the sense that adolescent friendship groups, or cliques, tend to demand conformity from their members. However, this demand for conformity among peers can be either for or against the standards of desirable behavior promoted by adults in the culture; in particular, it can be either for or against participation in reckless behavior. In some adolescent cliques, members are pressured to drive fast, have sex, try drugs, and otherwise break social norms; in others, the pressure is in the opposite direction, toward avoiding participation in reckless behavior.

Cultures differ in the extent to which they allow adolescents to form peer groups that encourage behavior that defies adult standards. The flexibility and freedoms of broad socialization make it possible for adolescents to form their own "youth culture" that encourages and rewards behavior (including reckless behavior) that adults would prefer to discourage. With narrow socialization, however, adults control and monitor the activities of adolescent peer groups to ensure that they promote conformity to the same standards of behavior that adults endorse. Among the Mbuti described by Colin Turnbull,[7] for example, arguing and fighting are socially unacceptable. When someone is guilty of these offenses, the adolescent boys of the village have the responsibility of appearing at the offender's hut early the next morning, shouting and yelling, beating on the roof and tearing off leaves and sticks. In this way, the adolescents reinforce the cultural standards of behavior in the offender as well as in each other, while also having an opportunity to express aggressiveness in a socially constructive way.

School

Schools characterized by broad socialization have a minimum of rules for dress, attendance, and conduct, and place a high emphasis on respecting and encouraging the individuality of each child. Schools characterized by narrow socialization have strict rules and firm punishments for violating them; often, such schools are founded on a narrow socialization belief system, for example, Catholicism, Judaism, or Islam. In general, school characteristics that imply narrow socialization are associated with lower levels of various types of reckless behavior, both within school and outside of it, even when academic aptitudes are taken into account. The school characteristics consistently found to be of importance are firm discipline, high expectations for performance, and a foundation in a belief system that provides moral guidance.[8]

Neighborhood and Community

Sociologists have studied for many decades the role of neighborhood and community characteristics in crime and delinquency. In general, these studies show that some types of reckless behavior are higher where there is high residential mobility and where communities are large. It may be that socialization is broader in larger communities than in smaller communities, in the sense that in larger communities there are fewer adults whom adolescents know and who may monitor and exercise authority over them.

However, this sociological research has taken place mostly in Western countries, and even communities with relatively narrow socialization within Western countries are less narrow in their socialization than communities in many non-Western, preindustrial cultures. In those cultures, socialization in the community is so narrow that adolescents rarely spend time away from the eyes of adults who know them and have authority over them, so adolescents rarely have the opportunity to participate in reckless behavior. Ethnographies such as Gilbert Herdt's on the Sambia in New Guinea demonstrate vividly the socialization practices of a community characterized by narrow socialization. The accounts of these anthropologists show how strongly obedience and conformity may be enforced by an entire community, and how little room such communities leave for antisocial recklessness,[9] in contrast to the relatively broad socialization of communities in the West.

Legal System

The legal system is not often mentioned in discussions of socialization, but as adolescents in many cultures grow into adolescence and spend an increasing amount of their time away from their families, the legal system is one of the forces that may monitor, restrict, and punish their behavior. Where socialization is broad on the legal dimension, there is a minimum of legal regulation of behavior, and the punishments for taking part in prohibited behavior (including many types of reckless behavior) tend to be lenient. In contrast, where legal socialization is narrow, the punishments are sure, swift, and harsh, and the legal system includes within its scope certain kinds of behavior that would not be subject to legal regulation under broad socialization. For example, consensual premarital sex is a crime that may be punished under the legal system in some Islamic countries.

In the West, perhaps the most vivid example of socialization by the legal system is in the area of automobile driving. A colleague and I studied adolescents in Denmark and found that they were much less likely to drive an automobile while intoxicated or at high speeds than are adolescents in the United States.[10] Danish adolescents often "drove" while intoxicated, but the vehicle typically used was a bicycle, not an automobile. The explanation for this difference lies not in cultural differences in family restrictions or peer pressure, but in the simple fact that the legal age for automobile driving is 18 in Denmark, but 16 in most U.S. states. Danish adolescents presumably have no less a developmental tendency for sensation seeking, egocentrism, and aggressiveness than American adolescents do, but because of restrictions set by the legal system, these tendencies are expressed (in part) through bicycles, not automobiles. Consequently, adolescents in Denmark (and in other Western European countries with a legal driving age of 18) have an automobile fatality rate that is markedly lower than in the United States.

Media

Many adolescents in the United States are immersed in media for much of their daily lives. The typical American adolescent listens to music for 4 hr a day and watches television for 2 more hr a day, and to this must be added time spent on videos, movies, and magazines, among other media forms. These media are generally an influence toward broad socialization, in that they encourage self-expression and immediate gratification, and discourage impulse control and self-restraint. They could be hypothesized to contribute to reckless behavior because reckless behavior is pleasurable, and adolescents imbibe from the media daily the message that what is pleasurable should be pursued without restraint, regardless of the consequences.

However, the influence of the media on adolescent reckless behavior is difficult to study precisely or directly, and the idea that the media incite reckless behavior among adolescents is still mostly theoretical and anecdotal. It should also be noted that the media can sometimes be an influence toward narrow socialization. For example, it could be argued that the decline in adolescent drug use that took place in the United States from the mid-1970s to the late 1980s was due at least partly to the extensive antidrug media campaign that also took place during that time.

Cultural Belief System

The cultural belief system is the ultimate source of socialization, because what parents, peers, schools, community members, and members of the legal system do as socializing agents is due at least in part to the beliefs they have learned from their culture. These are not necessarily religious beliefs, but any set of shared beliefs about what is good and bad, right and wrong, or healthy and unhealthy, including beliefs about the proper and most desirable goals of socialization. The belief system underlying narrow socialization is often religious—among the Amish, for example, or the Orthodox Jews—but the political ideology of communism has also served as a narrow-socialization belief system in countries such as China, Cuba, and North Korea, promoting obedience and conformity in the other sources of socialization. The belief system underlying broad socialization is one of expressive individualism: People should be allowed, even encouraged, to do whatever they wish as long as they do not cause direct harm to anyone else.

The cultural belief system not only provides the basis for socialization from the other sources, but also contributes directly to socialization. The nature of these beliefs is crucial to adolescents' understanding of the meaning and value of reckless behavior. If impulse control is highly valued in the culture, and obedience and conformity are considered high virtues—in short, if the cultural belief system is one of narrow socialization—most adolescents will refrain from reckless behavior and associate even the idea of such deviance with a level of shame and guilt strong enough to deter them from taking part in it, regardless of their inherent predispositions for sensation seeking, egocentrism, and aggressiveness. In contrast, if it is not impulse control but impulse gratification that is highly prized, if obedience and conformity are considered not virtues but weaknesses, if adolescents learn that reckless behavior is not shameful but condoned and even tacitly admired—in short, if the cultural belief system is one of broad socialization—adolescents will be more likely to express their tendencies toward sensation seeking, egocentrism, and aggressiveness as reckless behavior.

SUMMARY AND CONCLUSION

Adolescent reckless behavior results from the interaction between certain developmental characteristics that are heightened in adolescence—particularly sensation seeking, egocentrism, and aggressiveness—and the cultural socialization environment. Cultural socialization should be understood to include not just family and peers but also school, neighborhood and community, the legal system, the media, and the cultural belief system. All of these sources contribute to socialization and influence the rates and types of adolescent reckless behavior within a given culture.

Why would any culture allow adolescent behavior that disrupts the lives of other people and undermines social order, as reckless behavior often does? The reason is that cultures must accept some kind of trade-off in socialization between promoting individualism and self-expression, on the one hand, and promoting social order, on the other. Cultures characterized by broad socialization promote individualism and self-expression in an effort to produce autonomous, creative children and adolescents who express the full range of their potentialities. One price of promoting these goals is higher rates of adolescent reckless behavior; adolescent potentialities include sensation seeking, egocentrism, and aggressiveness, and if the expression of these tendencies is not tightly controlled by socialization, the result is likely to be high rates of reckless behavior. Cultures characterized by narrow socialization face a similar trade-off. They wish to promote obedience, conformity, respect for authority, and social order, and in doing so they achieve lower rates of disruptive and antisocial adolescent reckless behavior, and a safer, more orderly society. However, in promoting these goals, they run the risk of extinguishing what is brightest, liveliest, and most original in their adolescent children.

Notes

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4. J. Arnett, Reckless behavior in adolescence: A developmental perspective, *Developmental Review, 12,* 339–373 (1992).
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7. C. Turnbull, *The Forest People* (Doubleday, Garden City, NJ, 1962).
8. J.S. Coleman, T. Hoffer, and S. Kilgore, *High School Achievement: Public, Catholic, and Private Schools Compared* (Basic Books, New York, 1982).
9. G. Herdt, *The Sambia: Ritual and Gender in New Guinea* (Holt, Rinehart, & Winston, New York, 1987).
10. J. Arnett and L. Balle-Jensen, The cultural bases of risk behavior: Danish adolescents, *Child Development, 64,* 1842–1855 (1993).

Recommended Reading

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Morrison, D.M. (1985). Adolescent contraceptive behavior: A review. *Psychological Bulletin, 98,* 538–568.

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Chapter 13
The Maturation of Cognitive Control and the Adolescent Brain

B. Luna

Abstract Cognitive control, which allows us to guide behavior in a planned and voluntary fashion, continues to improve through adolescence in parallel with refinements in brain processes including synaptic pruning and myelination. The adolescent period is of special significance because the shift to mature adult-level cognitive processing begins to occur and because this period is vulnerable to errors in cognitive control evident in the emergence of major psychopathologic dysfunction and in risk-taking behavior. In this chapter, we review the literature characterizing the nature of developmental change in cognitive control of behavior and its relation to the brain maturational processes that occur at this time that affect brain function. Evidence from studies characterizing developmental improvements in speed of information processing, voluntary response inhibition, and working memory indicate that the ability to have cognitive control is present early in development and what continues to improve through adolescence is the ability to use this tool in a controlled and flexible manner. Functional magnetic resonance imaging and diffusion tensor imaging studies provide evidence that concurs with behavior results, indicating that the basic circuitry that supports cognitive control, including prefrontal systems, are on-line early in development and that a shift to increased functional integration throughout the brain underlies mature adult-level executive control. Viewed in the light of the current literature, the adolescent period is beginning to be understood as a necessary period of transition when there is a shift to integrated brain function that supports efficient and flexible control of behavior.

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F. Aboitiz and D. Cosmelli (eds.) *From Attention to Goal-Directed Behavior.*

Abbreviations

ACC	Anterior cingulate cortex
DA	Dopamine
DLPFC	Dorsolateral prefrontal cortex
EEG	Electroencephalography
fMRI	Functional magnetic resonance imaging
PET	Positron emission tomography
VLPFC	Ventrolateral prefrontal cortex

Introduction

This chapter reviews the literature on the interaction of brain and behavior underlying development through adolescence. First, we will define the nature of cognitive control to understand the precise mechanisms that are at the core of maturity. Second, we will review behavioral studies that depict the changes in cognitive control that occur at this stage. Third, we will review what is known about changes to brain structure during this period of development. Functional magnetic resonance imaging (fMRI) has provided a novel, noninvasive method for investigating the interface between brain and behavior which is appropriate for pediatric populations and affords an unprecedented spatial resolution to localize function at the whole-brain level. We will review the available fMRI data regarding changes in brain function that contribute to the integration of brain and behavior.

Adolescence typically refers to ages 12–17, taking into consideration variability in factors such as puberty and gender (Spear, 2000). Cognitive and brain structural changes, as well as pubertal/hormonal events, take place during this period and have a significant effect on behavior. We have a limited understanding of what processes support the developmental transition into peak cognitive performance and stabilization in young adulthood. The changes known to occur in adolescence suggest that plasticity and biologically determined mechanisms have a significant influence on development. Importantly, understanding normative development allows us to discern impaired or abnormal development. Major psychiatric disorders, such as affective disorders, anxiety, and schizophrenia, emerge during adolescence (Barlow, 1988; Angold, Costello, & Worthman, 1998; Waddington, Torrey, Crow, & Hirsch, 1991; Luna & Sweeney, 2004a), suggesting that vulnerabilities specific to this stage of development may be central to these disorders. Identifying the processes underlying normative maturation would allow us to investigate atypical processes in psychopathologic dysfunction, such as those described in Chap. 15 by Gaspar et al. Adolescence is also a time when sensation- and novelty-seeking behaviors peak across species and cultures; these behaviors may be necessary to develop the social skills needed to gain independence in adulthood (Steinberg, 2004; Arnett, 1992; Spear, 2000; Chambers, Taylor, & Petenza, 2003). Unfortunately, it is also during adolescence and young adulthood that experimental use and abuse of substances often begins (Chambers et al., 2003; Grant, 1997; Warner, Kessler, Hughes, Anthony, & Nelson, 1995). Investigation of the normative processes underlying the transition to mature behavior, including incentive processes, may inform our understanding of "risky" behavior in adolescence.

Cognition

Behavior can be elicited by endogenous or exogenous cues. *Exogenous* behavior is elicited by extraneous stimuli such as perceptual or emotional states. While not a reflex, which implies only spinal chord involvement, exogenously driven behavior is reflexive in nature, that is, it does not require a plan or goal. It is a fast, reactive response to an external cue, for example, looking at a suddenly appearing light. *Endogenously* driven behavior is behavior that is under *voluntary* control. Executive function and cognitive control refer to this type of behavior, which is goal-oriented and requires a plan to be executed. It is this type of behavior that the justice system uses to determine culpability. For example, you are cognitively controlling your behavior when you choose to reach for an object in the presence of alternative choices or choose not to look at a visual stimulus that would otherwise be compelling. Two main processes of cognitive control are response inhibition and working memory. At any given time we are confronted with a range of possible responses. Voluntary response inhibition allows a goal-directed response to override a more compelling, yet goal-inappropriate, response. Working memory is the ability to temporarily store and manipulate information for the purpose of a goal-directed response. These core cognitive processes support endogenously driven behavior and are crucial to cognitive development (Kail, 1993; Fry & Hale, 1996; Case, 1996; Dempster, 1993). Cognitive control is known to be supported by a widely distributed brain circuitry, in which prefrontal cortex plays a primary role (Fuster, 1997; Goldman-Rakic, Chafee, & Friedman, 1993). Whereas exogenously driven behavior is mature early in life, endogenously driven behavior continues to improve through adolescence.

Cognitive Maturation

Core executive abilities that are present early in life (Diamond & Goldman-Rakic, 1989; Levin, Culhane, Hartmann, Evankovich, & Mattson, 1991) demonstrate continued improvement through adolescence (Demetriou, Christou, Spanoudis, & Platsidou, 2002; Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Davies & Rose, 1999; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Asato, Sweeney, & Luna, 2006). Whereas much is known about the cognitive milestones achieved during infancy and childhood, relatively less information is available regarding the maturation of cognition into adolescence. Recent studies, however, have begun to elucidate the nature of this prolonged development in cognitive processes such as response inhibition and working memory, as well as in the complex cognitive abilities evident in typical neuropsychological assessments.

Speed of Processing

The speed at which information processing takes place is an essential component of cognitive control. The system must perceive the task demands, plan a behavior, and enact a response. Processing speed is important in both exogenously and endogenously driven responses, and it is believed to reflect the integrity of the brain processes underlying connectivity and functional integration (Kail, 1993; Kail, 1991; Luna et al., 2004). Processing speed has been found to decrease exponentially during childhood and adolescence across cognitive domains (Hale, 1990; Luna et al., 2004; Kail, 1993). The influence of processing speed, measured by reaction time, is evident in simple tasks with minimal cognitive demands, such as visually guided saccades (Luna et al., 2004; Fischer, Biscaldi, & Gezeck, 1997; Fukushima, Hatta, & Fukushima, 2000), manual reaction time (Elliott, 1970), and visual matching tasks (Klein & Foerster, 2001; Luna et al., 2004; Fry et al., 1996), as well as tasks that require cognitive planning (Luna et al., 2004). For example, reaction times for making an eye movement to a suddenly appearing visual stimulus reach maturity by 14–15 years, the same age at which subjects demonstrate maturity in the reaction time to initiate a cognitively driven eye movement (Luna et al., 2004) (Fig. 13.1). The age at which processing speed matures is highly consistent across tasks and

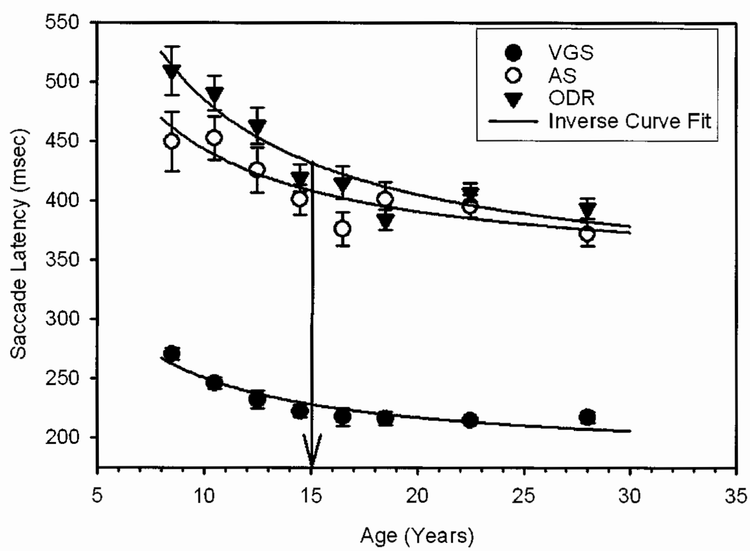

Fig. 13.1 Mean ± one standard error of the mean of the latency to initiate a saccade in the visually guided saccade task (*solid circles*), antisaccade (*open circles*), and the oculomotor delayed response (*triangles*). *Lines* indicate the inverse curve fit on the mean latency to initiate an eye movement response in milliseconds by age in years. *Arrows* depict the age at which change-point analyses indicate adult levels of performance were reached. (Reprinted with permission from Luna et al. 2004)

cognitive loads, suggesting that it is independent of cognitive level even though increasing difficulty results in longer reaction times. Processing speed contributes to the ability to engage cognitive processes, and its maturation may reflect increased efficiency from brain developmental processes, such as synaptic pruning and myelination (see later), that support improvements in cognitive processes, such as response inhibition and working memory.

Development of Voluntarily Guided Behavior from Late Childhood to Adolescence

Neuropsychological tests demonstrate that higher-order cognitive processes, including response inhibition and working memory, continue to develop through late childhood. This process is believed to be supported by prefrontal circuitry (Levin et al., 1991; Demetriou et al., 2002; Fry et al., 1996; Luna et al., 2004; Asato et al., 2006). Specifically, voluntary response suppression and working memory are executive processes (Fuster, 1997) that are essential to the emergence of adult-level cognitive control of behavior (Kail, 1993; Dempster, 1993). The ability to voluntarily suppress a response (i.e., response inhibition) underlies goal-directed executive behavior by allowing an individual to exert self-regulation to control task-irrelevant behavior by stopping prepotent responses and filtering distractors (Bjorklund & Harnishfeger, 1995; Dempster, 1992; Dempster, 1992). Working memory, the maintenance of information on-line (Baddeley, 1986), is crucial for goal-directed executive behavior by supporting response planning and preparation (Case, 1995). These executive processes are seen to break down during psychiatric illness (Sweeney, Takarae, Macmillan, Luna, & Minshew, 2004). Since cognitive maturation occurs concurrently with brain maturation, determining the neurobiological basis of cognitive development is crucial to understanding the biological influences on healthy and impaired development.

Development of Voluntary Response Suppression

The ability to voluntarily inhibit a reactive, task-irrelevant response improves into adolescence. Inhibitory tasks require that a reactive response be suppressed in favor of a planned response. In the go/no-go task, subjects are asked to press a button in response to a series of letters except in response to a target letter (e.g., *x*). The Stroop task requires subjects to suppress established reading responses and instead say the color of the ink of a word written in an incompatible color ("green" would be the correct response for the word *red* written in green). The Simon task requires subjects to respond to a color cue while suppressing the interfering location of the cue. In flanker tasks, subjects must suppress a response to the arrows surrounding a central arrow and instead report the direction of the central stimuli. In the stop-signal task, subjects are asked to voluntarily stop a reactive response after it has started. Fixation tasks require subjects to refrain from making reflexive eye movements away from fixation towards suddenly appearing peripheral visual targets. Finally, the antisaccade task is an inhibition task that has been used extensively in developmental, clinical, and monkey studies. In this task, subjects must suppress an eye movement to a suddenly appearing peripheral visual cue and instead make an eye movement to the mirror location. Errors are usually followed by an eye movement to the correct location, indicating that subjects understand the instructions but are unable to inhibit the reflexive response to look at the light. There is consistent improvement throughout childhood and adolescence across these tasks (Wise, Sutton, & Gibbons, 1975; Ridderinkhof, Band, & Logan, 1999; Bedard et al., 2002; Williams, Ponesse, Schachar, Logan, & Tannock, 1999; Luna et al., 2004).

Although younger subjects have a higher rate of inhibitory failures than older subjects, they are able to perform some trials correctly. Developmental improvement is seen in an increased number of correct responses. Since response inhibition cannot be performed by chance, the fact that children do perform some trials correctly indicates that younger subjects *can* suppress responses, but are unable to do so in a *consistent* manner. These results suggest that improvements in both the ability to compute inhibitory responses and the ability to sustain an inhibitory set support adult-level response inhibition. They also indicate that the ability to inhibit a response is present early in life and that development involves increased flexibility and control in using this ability. Late integration of frontal regions is believed to play an important role in the development of response inhibition, as evidenced by the fact that adults with frontal lesions are impaired on the antisaccade task (Guitton, Buchtel, & Douglas, 1985). However, it is the ability to integrate a large circuitry including frontal regions that is crucial to voluntary response inhibition. Inhibitory control is dependent on efficient top-down frontal modulation of behavior in which executive regions modulate the subcortical regions supporting reactive behavior. The circuitry underlying performance of the antisaccade task has been extensively delineated in single-cell monkey studies, making this task a well-informed, brain-based model of response inhibition (Everling & Munoz, 2000; Funahashi, Chafee, & Goldman-Rakic, 1993). Antisaccade studies have shown continued improvements in response suppression through adolescence, with maturation occurring around age 15 (Fischer et al., 1997; Munoz, Broughton, Goldring, & Armstrong, 1998; Fukushima et al., 2000; Klein et al., 2001; Luna et al., 2004). Single-cell studies in nonhuman primates indicate that preparatory attenuation of saccade-related neuronal activity in the superior colliculus (Everling, Dorris, Klein, & Munoz, 1999) and frontal eye fields (Everling et al., 2000) is crucial to a successful inhibitory response. These results suggest that response *planning* and preparation are essential for efficient top-down modulation of reflexive acts and that these abilities are still immature in adolescence. Taken together, these results indicate that voluntary response inhibition continues to develop through adolescence.

Development of Working Memory

Working memory is the ability to maintain and manipulate on-line information about stimuli that are no longer present in the external environment. Its primary role is to support goal-directed responses (Baddeley, 1986), and it has been found to underlie adult-level higher-order cognition (Bjorklund & Harnishfeger, 1990; Nelson et al., 2000; Dempster, 1993; Case, 1992). Similar to voluntary response suppression, working memory has a prolonged development (Swanson, 1999; Luciana & Nelson, 1998; Demetriou et al., 2002; Luna et al., 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004; Zald & Iacono, 1998). Spatial working memory tasks require that a response be guided by the on-line representation of a goal; the accuracy of the response is used as an index of working memory integrity. In many of these tasks, the location of a cue must be kept in working memory during a delay period, which may or may not include an interference stimulus or manipulation requirement (Swanson, 1999; Kwon, Reiss, & Menon, 2002). In the study reported by Zald el al. (1998), subjects touched the location of a previously presented cue after varying delays during which centrally presented words had to be verbalized. The results showed that across task delays and interference conditions, 14-year-olds showed immature performance. The memory-guided saccade task, also known as the oculomotor delayed response task, requires an eye movement response to be guided by the representation in working memory of the location of a previously presented visual cue. This task does not require manipulation of the representation in working memory and, as such, is a direct measure of maintenance. The memory-guided saccade task has been used in nonhuman primates to identify delay-dependent cells that sustain working memory throughout the brain, including in prefrontal cortex (Funahashi, Inoue, & Kubota, 1997). This task also has a protracted developmental trajectory (Luna et al., 2004). Luna et al. (2004) showed that the accuracy of the *initial* working memory response matures around 15 years of age; however, *subsequent* corrective eye movement responses, which are more precise, continue to mature into the second decade of life. A widely distributed brain circuitry underlies spatial working memory in adults and includes dorsolateral prefrontal cortex (DLPFC), the cortical eye fields, anterior cingulate cortex (ACC), insula, basal ganglia, thalamus, and lateral cerebellum (Hikosaka & Wurtz, 1983; Sweeney et al., 1996).

While infants demonstrate working memory abilities (Diamond et al., 1989), a range of working memory tasks concur in indicating a protracted development in working memory through adolescence. Variability is present in the timing within late childhood and adolescence when adult-level working memory performance is reached. This variability is due to differences in stimuli, domain, opportunity for using strategies, and amount of interference control. There is evidence for different developmental trajectories in spatial versus object working memory tasks that sometimes reflect earlier development in the spatial domain (van Leijenhorst, Crone, & van der Molen, 2007), while at other times indicate earlier development in the object domain (Conklin, Luciana, Hooper, & Yarger, 2007; Luciana, Conklin, Hooper, & Yarger, 2005). The ability to use different types of strategies can often account for discrepancies regarding the time of development. Tasks where verbal rehearsal strategies can be used often show protracted development that may be independent of working memory processes (Cowan, Saults, & Morey, 2006; van Leijenhorst et al., 2007; Conklin et al., 2007). Planning based on working memory information also appears to enhance working memory performance for a longer developmental trajectory that shows continued benefit into adulthood. For example, while young adolescents can perform at adult levels when required to identify the location of a previously presented target, improvements continue into adulthood when organized search of several targets is required (Luciana et al., 2005). Inhibitory control is integral to working memory performance especially in tasks where distractors are used during periods of maintenance (Roncadin, Pascual-Leone, Rich, & Dennis, 2007). Therefore, improved response inhibition can enhance working memory performance (Bjorklund et al., 1990; Dempster, 1981). Although working memory and inhibitory processes are often considered part of the same executive process, their relative contribution can be manipulated to discern their unique influences to development (Luna et al., 2004; Asato et al., 2006; Luciana et al., 2005). Another important factor that can affect working memory performance is the ability to detect errors and use these to inform future responses. There is growing evidence that there is a protracted development of processes used to monitor performance and errors that are still immature in adolescence (van Leijenhorst et al., 2007; Velanova, Wheeler, & Luna, 2008; Crone, Jennings, & van der Molen, 2004). These results indicate that while basic aspects of working memory are present early in development, there is continued specialization of working memory processes that continues into adulthood. Throughout the life span, working memory directed behavior follows an inverted-U shape: there is improvement through adolescence, stabilization in adulthood, and a decrement in elderly years (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006).

Given the delayed development of core cognitive processes, it is not surprising that there is protracted development in the performance of complex cognitive tasks (for reviews see Diamond, 2002; Welsh, 2002). Complex cognitive tasks are those that involve multiple cognitive processes, including attention, response inhibition, and working memory as well as language processing and mathematical abilities. Typical tasks include those that require planning and rule-guided behavior, for example, the Wisconsin Card Sorting Test, which requires subjects to deduce the randomly changing rule that determines correct responses; the Tower of London, in which subjects must arrange stimuli in a certain predetermined order in a minimal number of steps; and the Contingency Naming Test, in which subjects are given rules to produce a Stroop-like response. Failures in set maintenance and in planning are often indicated to underlie the protracted development of performance in complex cognitive tasks (Chelune & Thompson, 1987; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991). However, developmental improvements in core cognitive abilities such as processing speed, working memory, and inhibition have been found to modulate development of these tasks (Asato et al., 2006).

In sum, there are aspects of working memory that appear early in development. However, there are improvements throughout adolescence in the ability to perform complex tasks, be more precise, use strategies, and control distraction, resulting in an efficient and adaptable working memory system that is able to support higher-order cognitive processes, such as abstract thought, and enhances decision making. Although an immature system may be able to process simple working memory demands, inefficient processing of more complex demands may result in poor decision making.

Maturation of Brain Structure

At the same time that improvements in cognitive control are emerging, structural brain changes are occurring that are believed to support mature behavior. The gross morphology of the brain, including the degree of cortical folding (Armstrong, Schleicher, Omran, Curtis, & Zilles, 1995), overall size, weight, and regional functional specialization, is adult-like by early childhood (Caviness, Kennedy, Bates, & Makris, 1996; Giedd, Snell, et al., 1996a; Reiss, Abrams, Singer, Ross, & Denckla, 1996). The skull thickens throughout childhood, accounting for increases in head size. Once the basic morphology is in place, brain processes occur that are believed to support the molding of brain structure to fit the biological and external environments of the organism. Some well-characterized mechanisms that occur throughout adolescence are synaptic pruning and increased myelination (Huttenlocher, 1990; Yakovlev & Lecours, 1967; Jernigan, Trauner, Hesselink, & Tallal, 1991). These processes lead to more efficient neuronal processing, which supports mature cognitive control of behavior. We are born with an excess of synaptic connections, which decrease in number throughout development owing to activity-dependent stabilization, that is, the connections that are used remain and those that are not used are eliminated (Rauschecker & Marler, 1987). Synaptic pruning promotes efficient integration of regional circuitry, enhancing the capacity and speed of information processing (Huttenlocher, 1990; Huttenlocher & Dabholkar, 1997). Myelination, which speeds neuronal transmission, also increases the efficiency of information processing and supports the integration of the widely distributed circuitry needed for complex behavior (Goldman-Rakic et al., 1993). These structural changes are believed to underlie the functional integration of frontal regions with the rest of the brain (Thatcher, Walker, & Giudice, 1987; Chugani, 1998; Luna & Sweeney, 2004b). Immature myelination in adolescence may limit top-down modulation of behavior, affecting cognitive control (Casey, Tottenham, Liston, & Durston, 2005; Luna et al., 2004; Thatcher, 1991; Chugani, Phelps, & Mazziotta, 1987). Recent structural neuroimaging studies have indicated reductions in gray matter throughout cortical association areas, notably the frontal and temporal regions (Gogtay et al., 2004; Toga, Thompson, & Sowell, 2006; Giedd et al., 1999; Sowell, Thompson, Tessner, & Toga, 2001; Paus et al., 1999), as well as the basal ganglia (Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). This pattern continues past adolescence and may reflect both reduced synaptic connections and increased myelination. Diffusion tensor imaging studies indicate a continued increase in frontal white matter integrity throughout childhood, providing evidence for continued myelination with age (Klingberg, Vaidya, Gabrieli, Moseley, & Hedehus, 1999). These findings provide a new outlook on brain development, which had originally been thought to progress from posterior to anterior regions, with prefrontal cortex developing last (Hudspeth & Pribram 1990; Stuss 1992; Diamond & Taylor 1996; Luciana & Nelson, 1998). Instead results suggest that the functional integration of a widely distributed circuitry characterizes late development into adulthood (Luna et al., 2004).

Late development is also evident in the basal ganglia (Giedd, Vaituzis, et al., 1996b; Sowell et al., 1999; Toga et al., 2006) and orbitofrontal cortex (Gogtay et al., 2004), which may limit adolescents' ability to properly assess valence (reward and punishment). Evidence indicates that during adolescence, there is greater activity in excitatory dopamine (DA) systems than in inhibitory 5-hydroxytryptamine systems, resulting in an imbalance between reward and suppression mechanisms (Lambe, Krimer, & Goldman-Rakic, 2000; Chambers et al., 2003). Nigrostriatal DA neurons and components of the basal ganglia show their highest activity in childhood, then decrease exponentially during the first three decades of life (Segawa, 2000). D1 receptors in ventral striatum develop earlier than D2 receptors, which continue to decrease throughout adolescence (Meng, Ozawa, Itoh, & Takashima, 1999). D2 receptors help guide voluntary saccades (Kato et al., 1995). The number of DA transporters, which remove DA from the synapse and are primarily found in the striatum, peaks during adolescence, as does myelination in this region (Meng et al., 1999). Projections from the basal ganglia that ascend to the thalamus via striatal pathways, which provide loops with frontal systems, continue to mature in adolescence (Segawa, 2000). Animal studies indicate that DA inputs to prefrontal cortex peak in adolescence, which increase inhibitory inputs to prefrontal cortex, resulting in decreased excitatory outputs (Lewis, 1997; Spear, 2000). The effects of brain immaturities have lead to two schools of thought regarding reward processing in adolescence. One proposal is that adolescence is a time of low motivation which leads to the search for more salient rewards, perhaps resulting in substance abuse (Spear, 2000; Castellanos & Tannock, 2002). Others believe that adolescence is a time of exaggerated reward response which leads to sensation seeking and risk-taking behavior (Chambers et al., 2003). Both arguments are supported by the effects of the immaturity of the system. An alternative proposal is that adolescents demonstrate low motivation when there is a low cognitive load requiring little effort, such as in reaction time tasks (Bjork et al., 2004), but overactivity of the reward system when cognitive effort is required (Ernst et al., 2005; Galvan et al., 2006) (see later).

Taken together, these studies indicate that the brain systems that are crucial for exerting cognitive control over behavior and processing rewards are still immature during adolescence. These immaturities result in a system that is able to exert cognitive control, but in an inconsistent manner with limited flexibility and motivational control. In other words, the basic elements are established, but refinements are needed to support the necessary efficiency in circuit processing to establish reliable executive control.

Pubertal Maturation and Cognitive Development

Concurrent with cognitive development and brain maturation in late childhood and adolescence is pubertal development. During puberty, neurotransmitters and glial cells regulate neuronal control of gonadotropin-releasing hormone, which stimulates the secretion of hormones in the pituitary gland, resulting in ovarian development in females and spermatogenesis in males (Ojeda, Ma, & Rage, 1995). The timing of this process is determined by age as well as metabolic and neuronal factors. Changes in gonad hormone levels have direct effects on molecular mechanisms throughout the brain (McEwen, 2001). There is evidence that gonad hormones may influence cortical development, which may help account for sex differences in cognitive development (Clark & Goldman-Rakic, 1989). A direct way to determine pubertal timing is by assessing bone age using X-rays, which is counterindicated for normative pediatric studies. Most methods for determining pubertal timing, such as breast and testicular growth in pediatric examination, age of menarche onset, age of mutation (voice change for men), increased testosterone in saliva, peak height growth velocity, Tanner staging, Tanner physical examination, and Tanner self-report (Duke, Litt, & Gross, 1980; Tanner, 1962), measure the emergence of secondary characteristics that result from puberty and occur later than the onset of hormonal changes. Tanner staging, though limited owing to its subjective nature which can lead to variability, is the least invasive measure of pubertal timing. Hormonal changes are well recognized to affect mood and social processes (Alsaker, 1996). Hormonal changes affect sex steroid receptors in the hippocampus which support novelty seeking and regulate DA in the nucleus accumbens (Chambers et al., 2003). Pubertal changes may thus have a direct link to reward sensitivity. On the other hand, it has been harder to establish direct links between pubertal changes and cognitive processes. Some studies have found a link between spatial abilities and pubertal timing (Petersen, 1976; Waber, Mann, Merola, & Moylan, 1985), whereas others have not (Strauss & Kinsbourne, 1981; Orr, Brack, & Ingersoll, 1988). To characterize changes during adolescence, it is important to delineate the parallel systems that undoubtedly contribute to how cognitive control will manifest itself in behavior and, more importantly, to how it may play a role in risk-taking behavior and the vulnerability of this stage to psychopathologic dysfunction.

Development of Brain Function

The investigation of how the brain functions during the exertion of cognitive control is central to understanding the interface between cognitive control and immaturities in brain structure. In this manner, we can begin to understand the consequences of brain immaturities and the basis of behavior in adolescence. Moreover, characterizing a normative template of brain function can provide a window into the impaired development evident in major psychiatric disorders.

The main approaches that have been used to understand this relationship are electroencephalography (EEG) and neuroimaging techniques, such as positron emission tomography (PET) and, more prominently, fMRI. Whereas EEG is used extensively to study the brain basis of cognition in infancy, it has rarely been used to assess changes throughout the life span. A landmark study investigated changes in EEG coherence throughout childhood and into adulthood (Thatcher et al., 1987). The results showed an increase in coherence of EEG activity across neocortical regions throughout adolescence, primarily between frontal and other cortical areas, with differentiation in the left hemisphere and integration in the right hemisphere. These findings have been supported by PET results demonstrating immaturities in the local cerebral resting metabolic rates of frontal, parietal, and temporal regions that only begin to mature in adolescence (Chugani, 1998). Taken together, the results indicate the late integration of the frontal lobe into the widely distributed brain circuitry supporting cognitive control of behavior. However, these procedures have limited spatial resolution and do not allow the identification of circuit-based changes in the brain. PET is particularly counterindicated in pediatric studies because of the invasive nature of radioactive isotopes that are injected to localize brain function. In contrast, fMRI is a noninvasive neuroimaging procedure that allows in vivo investigation of brain activity underlying cognitive function in pediatric populations. Furthermore, fMRI provides high spatial resolution, localizing brain function on the order of millimeters. It measures regional changes in blood oxygenation levels produced by increases in metabolic demands resulting from neuronal activity that supports the cognitive processes of interest. It is an indirect measure of neuronal activity, but one that has increasingly been found to be tightly coupled with neuronal activity (Logothetis & Pfueffer, 2004).

A burgeoning literature has begun to characterize adolescent development using fMRI. As fMRI requires subjects to remain still and follow instructions, it is usually performed on children older than 6–8 years. This caveat has opened the door for the emergence of developmental studies that investigate later stages of development. Cognitive control has been investigated by probing the developmental differences supporting inhibitory control, working memory, and rule-guided behavior. The interpretation of fMRI results is an area of debate as age differences may result in either increases or decreases in activity. One theory of age-related decreases suggests that maturation is characterized by a focalization of activity due to increased sophistication of neuronal processes (Durston et al., 2006). However, many studies also show age-related increases in activity and the recruitment of regions that do not participate at younger ages. One approach is to predefine function in the adult system as the mature goal state and function that deviates from this standard as immature. Age-related decreases could indicate focalization of activity as well as a decreased need for recruitment of particular regions. Age-related increases could reflect immaturity in the structure of the circuits supporting mature performance.

Development of Brain Function Underlying Voluntary Response Inhibition

Studies investigating developmental differences in response inhibition have consistently found that activity in prefrontal cortex increases from childhood to adulthood. A failure to recruit ventrolateral prefrontal cortex (VLPFC), a key region supporting response inhibition (Blasi et al., 2006), was found in subjects of 8–12 years of age compared with adults while performing a mixed go/no-go (inhibition of an established response) and flanker (interference control) task (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002 a, b). These results are supported by another study that found increased activity in prefrontal regions in adults (22–40 years old) compared with adolescents (12–19 years old) in a task requiring the suppression of an established response (Rubia et al., 2000). Age-related increases in prefrontal function have also been found during a Stroop interference task (Adleman et al., 2002), as adolescents demonstrate reduced prefrontal recruitment in comparison with adults, whereas their parietal activity is mature. On the other hand, age-related decreases in the inferior frontal gyrus and increases in the middle frontal gyrus were found from 8 to 20 years of age while subjects were performing a go/no-go task (Tamm, Menon, & Reiss, 2002). These results were interpreted as indicating that decreased activity in inferior frontal gyrus are due to developmental improvements in the ease of performing the task, whereas increases in middle frontal gyrus reflect the specialization of this region for inhibitory control. Studies that test subjects across the life span indicate overall age-related increases in prefrontal regions that are associated with improved inhibitory performance. In a study looking at 7–57-year-olds, overall age-related increases in activity of inferolateral prefrontal cortex and frontostriatal systems were correlated with improved performance during a Stroop task (Marsh et al., 2006). Similarly, in a study looking at 10–47-year-olds performing a stop-signal task, overall age-related increases in right inferior prefrontal cortex were found during successful inhibition (Rubia, Smith, Taylor, & Brammer, 2007). Additionally, correlational analyses indicated age-related integration of frontostriatothalamic and frontocerebellar neural pathways for inhibitory control. Another study comparing 10–17-year-olds with 20–43-year-old adults found similar increases in frontostriatal regions that correlated with improvements in a battery of inhibitory tasks (go/no-go, Simon, and attentional set-shifting (Rubia et al., 2006). These results confirm earlier findings indicating that frontal regions supporting improvements in performance show age-related increases (Rubia et al., 2000).

Previous studies have assumed that the developmental progression from childhood to adolescence to adulthood is linear; however, there is evidence that development is stagelike (Thatcher et al., 1987) and that adolescence may be qualitatively different from either childhood or adulthood. Taking a systems-level approach at defining developmental differences in the circuit-based processes supporting response inhibition, Luna et al. (2001) reported both increases and decreases that differed depending on when in development they occurred. Subjects 8–30 years of age were studied using the antisaccade task and analyses compared children (8–12 years old), adolescents (13–17 years old), and adults (18–30 years old). Activity in DLPFC, which was defined as the middle frontal gyrus, showed an increase from childhood to adolescence but a decrease from adolescence to adulthood. Adults showed increased activity in premotor areas and parietal eye fields, as well as cerebellum. Age-related increases in parietal and cerebellar regions have also been found in other developmental studies of inhibition (Rubia et al., 2006; Bunge et al., 2002 a, b). These results suggest that there may be stagelike changes in development: from childhood to adolescence the DLPFC, which is crucial for inhibitory control (Fuster, 1997; Fassbender et al., 2004), shows increased participation matching increased performance; however, from adolescence to adulthood, when performance does not change dramatically, there is a decrease in prefrontal activity, indicating a specialization of this region for cognitive control. In other words, although performance is stable from adolescence to adulthood, adolescents must exert more executive effort to do the task. In adult studies, prefrontal activity increases with higher cognitive loads. In this manner, adolescent brain function during inhibition tasks is similar to adult brain function during more difficult tasks. Difficult tasks have a higher probability of error; thus, although adolescents may behave like adults, they require more effort, which makes them more vulnerable to error (Luna et al., 2004).

An important aspect of inhibitory performance is the ability to detect errors and use this information to influence subsequent responses. Error detection and performance monitoring are integral to cognitive control and the ACC has been identified as the primary structure where error is processed (Braver, Barch, Gray, Molfese, & Snyder, 2001). Developmental studies have begun to find that there are immaturities in error processing during response inhibition through adolescence (Rubia et al., 2007; Velanova et al., 2008). Using a stop task where performance was equivalent across ages, Rubia et al. (2007) found increases for adults relative to children in rostral ACC and right inferior prefrontal cortex during error commission. Our own studies have indicated not only increased activity in ACC during errors of inhibition, but we also found that this was specific to different stages of error processing. We found that ventral ACC had equivalent activation in initial stages of error processing across childhood and adolescence; however, a later second stage of error processing showed that only adults recruited the dorsal ACC, reflecting immaturities even in adolescence (Velanova et al., 2008) (Fig. 13.2). These results imply that while the detection of errors may be on-line early in development, later stages that may influence subsequent behavior may have a protracted development.

Taken together, developmental fMRI studies indicate that prefrontal cortex is involved in response inhibition early in childhood and that its relative participation becomes more robust and focal with maturity. The results support the early contribution of prefrontal cortex to response inhibition. However, the ability to consistently inhibit responses characterizes the transition to mature performance, and this process necessitates a widely distributed circuitry and integrated brain system (Goldman-Rakic, 1988). The fact that functional integration across neocortex is

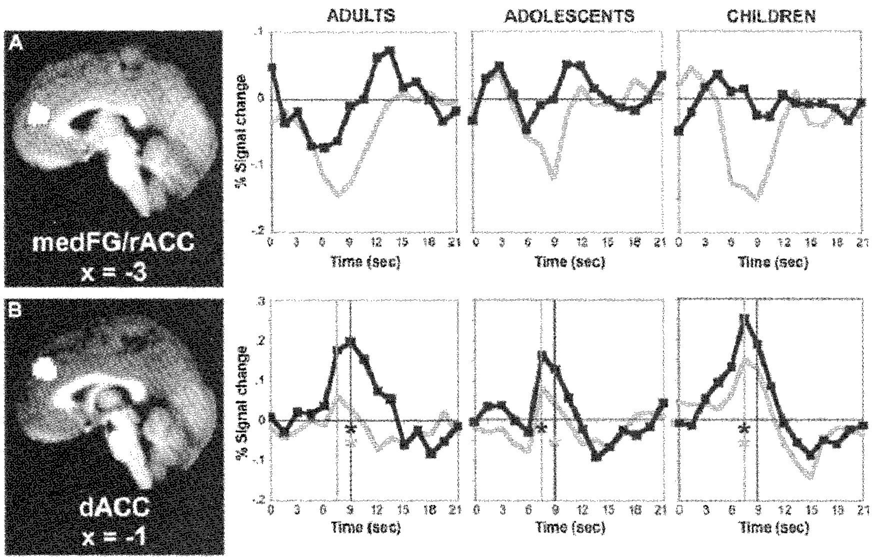

Fig. 13.2 (**a**) No age differences in the rostral anterior cingulate cortex region during correct (*black lines*) and incorrect (*gray lines*) inhibitory responses. (**b**) Greater activity in adults in the dorsal anterior cingulate cortex region for incorrect inhibitory responses. *rACC* rostral anterior cingulate cortex, *dACC* dorsal anterior cingulate cortex. (Reprinted with permission Velanova et al. 2008)

present throughout adolescence (Thatcher et al., 1987; Chugani, 1998) indicates that in conjunction with developmental improvements in the intrinsic computational capacity of prefrontal cortex there is increased integration of this and other brain regions during adolescence. Several studies have indicated that additional areas become active in adulthood, including parietal, striatal, and cerebellar regions (Luna et al., 2001; Tamm et al., 2002; Rubia et al., 2007; Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002 a, b), which may establish an efficient circuitry supporting mature response inhibition through connections with prefrontal cortex.

While there is variability across studies in the specific structures showing developmental differences in brain function, there is agreement that some functional immaturities are present throughout adolescence. Immaturities in brain function in the presence of mature performance could indicate a fragile system that may be particularly vulnerable to impairment, as evident in psychopathologic dysfunction and risk-taking behavior. Characterizing a normative system allows the investigation of the impaired development usually associated with failures of cognitive control, as seen, for example, in conditions such as attention deficit hyperactivity disorder, Tourette's syndrome, and autism (Luna & Sweeney, 1999; Luna et al., 2002). It also helps us begin to understand the mechanisms underlying risk-taking behavior in adolescence.

Development of Brain Function Underlying Working Memory

Many studies have characterized the changes in brain function that underlie the development of working memory. Working memory tasks involve different stages of information processing: encoding task demands, maintaining information on-line, and, following Baddeley's influential model (Baddeley, 1986), manipulating information during maintenance. Most studies have focused on characterizing maintenance systems, but some studies have looked at developmental changes during manipulation. Collectively, developmental studies indicate that the integration of prefrontal and parietal systems is crucial to the maturation of working memory. Early studies, focusing on children younger than 12 years, identified areas that were recruited by different age groups. These studies used spatial working memory tasks in which subjects had to remember the location of a visual cue (Thomas et al., 1999; Nelson et al., 2000) or simple n-back tasks in which subjects had to press a button in response to a letter that was repeated with one intervening letter (e.g., A-S-A; Casey et al., 1995). The results showed that children, like adults, are able to recruit prefrontal and parietal regions involved in working memory; however, the degree of activation was not compared. Using a categorical working memory task that requires multiple cognitive components (object processing and language), one study found that children recruit premotor/striatal/cerebellar networks rather than the ventral prefrontal and inferior temporal regions recruited by adults (Ciesielski, Lesnik, Savoy, Grant, & Ahlfors, 2006). These results suggest that core working memory systems are available early in childhood but may fail to be recruited in more complex working memory tasks. In older samples, increased participation of DLPFC and parietal cortex has been found from childhood to adolescence (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Scherf, Sweeney, & Luna, 2006; Klingberg, Forssberg, & Westerberg, 2002; Olesen, Macoveanu, Tegner, & Klingberg, 2006a). Klingberg et al. (2002) found age-related increases in activity of superior frontal and intraparietal cortex when 9–18-year-old subjects had to remember the location of a visual target. Crone et al. (2006) found that although 8–12-year-olds recruited VLPFC for maintenance, they failed to recruit DLPFC during the manipulation of working memory when they had to reorder the presentation of three pictures of objects. By adolescence, activation in DLPFC was adult-like. In a study that required subjects to remember locations of circles, age-related increases in prefrontal activity were found in adults compared with 13-year-old children; however, when a distractor was present, children showed more prefrontal activity, reflecting their difficulty inhibiting competing stimuli (Olesen, Macoveanu, Tegner, & Klingberg, 2006b). Scherf et al. (2006) used the oculomotor delayed response task to focus on the maintenance aspect of working memory. Activation in DLPFC was found only minimally in children, and its highest level of participation was in adolescents. Children relied more on basal ganglia and insula, whereas adults recruited additional regions, including temporal regions. This study considered brain function at the systems level and found that with maturity a larger and more distributed circuitry supported brain function (Fig. 13.3). Increases in activation have also been associated with increases

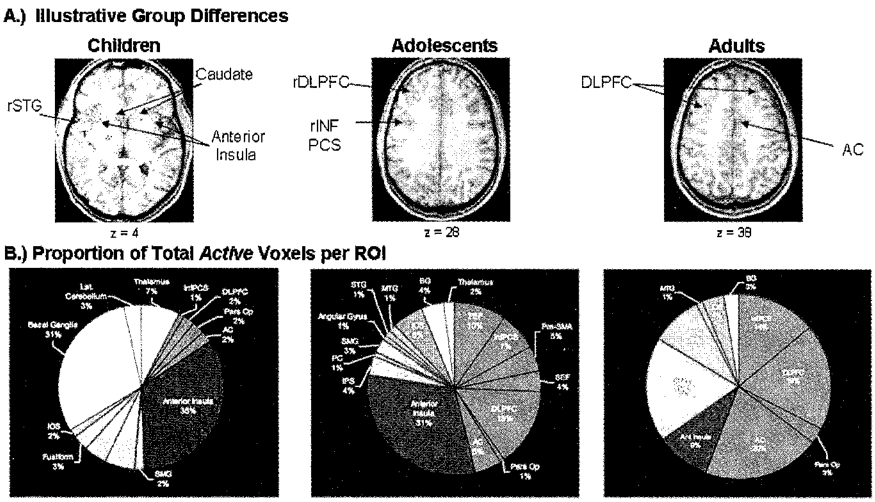

Fig. 13.3 (**a**) Axial slices illustrating regions of age group differences. (**b**) Distribution of regions with working memory related activity for each age group. While children showed predominance in the recruitment of basal ganglia and insula, adolescents showed a bias towards insula and right dorsolateral prefrontal cortex. By adulthood, activity is more distributed with several regions sharing control in working memory. *DLPFC* dorsolateral prefrontal cortex, *rDLPFC* right dorsolateral prefrontal cortex, *ROI* region of interest, *AC*, *PCS*, *rINF*. (Reprinted with permission from Scherf et al. 2006)

in the integrity of white matter in frontoparietal regions (Olesen, Nagy, Westerberg, & Klingberg, 2003); however, the interaction of parietal and prefrontal regions appears to be even more strongly associated with performance (Edin, Macoveanu, Olesen, Tegner, & Klingberg, 2007).

Development of Brain Function Underlying Reward Processing

A crucial aspect of cognitive control is the manner in which motivation influences optimal performance. Striatal and DA systems known to support motivation continue to mature during adolescence. fMRI studies have begun to characterize the developmental trajectory of reward/motivation processing through adolescence (van Leijenhorst, Crone, & Bunge, 2006; Galvan et al., 2006; Eshel, Nelson, Blair, Pine, & Ernst, 2007; Galvan, Hare, Voss, Glover, & Casey, 2007). Several studies have found that rewards differentially affect activity in reward-related circuitry during adolescence. Using a gambling task where subjects had to guess the winning response, Ernst et al. (2005) found that adolescents have *elevated* activity in the nucleus accumbens during reward anticipation, whereas adults have *decreased* activity in the amygdala to reward omission. During the selection of risky choices, adolescents showed decreased activity of orbital frontal cortex, VLPFC, and ACC, indicating limited executive control (Eshel et al., 2007). Similarly, Galvan et al. (2006) used a reward-association task and found that adolescents showed elevated activity in the nucleus accumbens compared with adults, who showed elevated activity in orbital frontal cortex. Activity in the nucleus accumbens was highest in individuals who rated themselves as engaging in risky behavior (Galvan et al., 2007). In contrast to the findings in previous reports, Bjork et al., (2004), using a reaction time task with relatively low cognitive load, found that adolescents showed *decreased* activity compared with adults in the ventral striatum when they were anticipating responding for a reward, but were not different from adults in activity supporting gain outcomes. Discrepant results may be due to differences in the cognitive load of the response: one study had very low demands in a reaction time task (Bjork et. al., 2004) that may lead to underactivity in the reward system and the others had higher cognitive demands when subjects had to anticipate and choose a response and showed overactivity of the reward system (Ernst et al., 2005; Galvan et al.,2006). Work in the rat model system suggests that the nucleus accumbens is predominantly involved in goal-directed behavior associated with rewards (Carelli, 2004). Alternatively, adolescents may have delayed striatal processing that is underactive initially during reward assessment but is overactive during reward feedback. This possibility still needs to be explored.

Cognitive and Brain Maturation

Traditional theory indicates that higher-order cognitive development is due to a late maturation of frontal circuitry (Hudspeth & Pribram, 1990; Stuss, 1992; Diamond & Taylor, 1996; Luciana et al., 1998). This viewpoint is based on early studies (Huttenlocher, 1990; Yakovlev et al., 1967) showing a late stabilization of synaptic pruning and myelination in frontal, relative to visual, cortex in humans and is not consistent with nonhuman primate studies that show concurrent development throughout the neocortex. This view suggests that executive abilities do not emerge until the brain is fully mature and that abnormalities in development are localized in the frontal cortex. In contrast, a careful review of these studies, along with the integration of recent magnetic resonance (Giedd et al., 1999; Sowell et al., 2001; Paus et al., 1999) and histological (Benes, 1998) data, demonstrates a dynamic late maturation *throughout* association cortex (Rakic, Bourgeois, Eckenhoff, Zecevic, & Goldman-Rakic, 1986). The last regions to show thinning of gray matter are the association areas of each lobe, with temporal regions showing the most protracted development, presumably due to the continued specialization of language (Gogtay et al., 2004). In this manner, the expansion of functional integration coupled with enhanced regional computational capacity allows for the more efficient use of the widely distributed circuitry underlying adult-level higher-order cognition (Goldman-Rakic et al., 1993). Adolescence may mark the beginning of a qualitatively different stage in the brain–behavior relationship. Newly established distributed circuitry, rather than regional circuitry, may govern behavior, reflecting the transition from exogenous to endogenous control. This approach suggests that although development in childhood is characterized by gaining abilities, maturation in adolescence consists of a qualitative difference in the use of existing capabilities. In this new framework, the emergence of psychiatric illness can be viewed not as a loss of cognitive abilities, but as an inability to shift to this new mode of operation.

Summary

Behavioral studies indicate that there are important improvements in cognitive control throughout adolescence. Although the basic tools that enable cognitive control are present early in development, the ability to use these tools in a consistent, flexible manner continues to improve through adolescence. Despite the often adult-like cognitive control of behavior exhibited by adolescents, these processes are still not supported by mature brain systems. There is evidence of immaturity, namely, in the ability of prefrontal systems to integrate with other brain regions to efficiently coordinate a planned action. Voluntary control of behavior underlies decision making and is supported by top-down modulation of behavior, which enables prefrontal systems to implement goal-driven behavior by efficiently coordinating with regions involved in processing behavioral demands and enacting responses. The transition to mature behavior is characterized by a shift to distributed function supporting cognitive control. Synaptic pruning enhances the ability to support complex computations necessary for higher-order behavior, such as the ability to enact plans that allow for response inhibition and retaining representations of goals in working memory. Myelination supports the ability to tap into a widely distributed circuitry that allows executive regions to control other regions that determine responses. This transition in adolescence may be a necessary stage of development that supports the effective sculpting of the brain to optimally match the unique environment of the individual. There are still many issues that need to be understood, such as the precise mechanisms that limit mature cognitive control, the immaturities in the brain that hamper efficient functional integration, and the ways in which these factors go awry in clinical populations.

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Review article

The Teen Brain: Insights from Neuroimaging

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Abstract: Few parents of a teenager are surprised to hear that the brain of a 16-year-old is different from the brain of an 8-year-old. Yet to pin down these differences in a rigorous scientific way has been elusive. Magnetic resonance imaging, with the capacity to provide exquisitely accurate quantifications of brain anatomy and physiology without the use of ionizing radiation, has launched a new era of adolescent neuroscience. Longitudinal studies of subjects from ages 3–30 years demonstrate a general pattern of childhood peaks of gray matter followed by adolescent declines, functional and structural increases in connectivity and integrative processing, and a changing balance between limbic/subcortical and frontal lobe functions, extending well into young adulthood. Although overinterpretation and premature application of neuroimaging findings for diagnostic purposes remains a risk, converging data from multiple imaging modalities is beginning to elucidate the implications of these brain changes on cognition, emotion, and behavior.

Keywords: Child; Adolescent; Development; MRI; DTI; MT; fMRI; Gray matter; White matter

"A science of the mind must reduce . . . complexities (of behavior) to their elements. A science of the brain must point out the functions of its elements. A science of the relations of mind and brain must show how the elementary ingredients of the former correspond to the elementary functions of the latter." — William James, The Principles of Psychology, 1890

For most of the 117 years since William James's formulation of the quest to link biology with behavior, the study of the adolescent brain remained inaccessible. Wrapped in a tough leathery membrane, surrounded by a protective moat of fluid, and completely encased in bone, the brain is well protected from falls, attacks from predators, and the curiosity of neuroscientists. The invention of imaging technologies such as x-rays, computed tomography, and positron emission tomography offered some progress, but the reliance on ionizing radiation precluded the ethical application to studies of healthy subjects.

The advent of magnetic resonance imaging (MRI) finally broke through the formidable barrier thwarting the pursuit of James's vision. MRI combines radio waves, strong magnetic fields, and sophisticated computer technology to provide detailed information about the anatomy and physiology of the brain without the use of ionizing radiation. The lack of ionizing radiation allows not only scanning in healthy children but also repeated scans in the same individual over the course of development.

This manuscript summarizes results of on ongoing, longitudinal, structural MRI project looking at typical and atypical brain development. Because adolescence does not have a precise biologic definition and the onset of puberty can vary by as much as 6 years in typical development, data are presented across ages 3–27 years, and readers can examine specific ages of interest in the figures accompanying the text. In addition, an Addendum after the main text provides further discussion of technical aspects of image acquisition and analysis, as well as a brief overview of some other imaging modalities used in adolescent research.

NIMH Child Psychiatry Branch Longitudinal Brain Imaging Project

Begun in 1989 under the direction of Markus Krusei, M.D., the Child Psychiatry Branch (CPB) of the National

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Institute of Mental Health has been conducting a longitudinal study of brain development in health and illness. The study design is for participants to come to the National Institutes of Health at approximately 2-year intervals for brain imaging, neuropsychologic and behavioral assessment, and collection of DNA. As of September 2007, we have acquired approximately 5000 scans from 2000 subjects.

From the outset the study has included typically developing people, both to provide a comparison from which to assess pathology and to explore mechanisms and timing of brain development as a guide to interventions. The sample of participants who have remained free of psychopathology (and constrained to only one subject per family for statistical independence), consists of 829 scans from 387 subjects aged 3–27 years. The data for the following sections regarding quantification of brain structure sizes are largely from this cohort. The emphasis on this single source is not to devalue the many excellent contributions of other investigators, but to provide an integrated account from the world's largest collection of child and adolescent brain MRI scans with data acquired using uniform screening and assessment batteries, the same scanner, and the same methods of image analyses.

Data regarding brain physiology, such as that from functional MRI (fMRI) or other imaging modalities, are drawn from the literature reported by other investigators or from collaborative work with other neuroimaging teams. Although there is high optimism for the novel and complementary information potentially provided by the newer imaging methods currently the number of subjects for whom structural MRI (sMRI) is available dwarfs that of the other modalities. As opposed to the data set of more than 1000 for sMRI, no pediatric study using fMRI, diffusion tensor imaging (DTI), or magnetization transfer (MT) has been reported with a sample of more than 100.

Developmental Anatomic Trajectories During Typical Childhood and Adolescence

Total Cerebral Volume

In the CPB cohort, total cerebral volume peaks at 10.5 years in girls and 14.5 years in boys [1]. By age 6 years, the brain is at approximately 95% of this peak (Figure 1a). Total cerebral volume decreases during adolescence were not previously detected with postmortem data [2,3] or cross-sectional MRI studies [4,5]. Consistent with the adult neuroimaging literature [6], mean total cerebral volume is approximately 10% larger in boys. Total brain size differences should not be interpreted as imparting any sort of functional advantage or disadvantage. Gross structural measures may not reflect sexually dimorphic differences in functionally relevant factors such as neuronal connectivity and receptor density. Of note is the high variability of brain size even in this group of rigorously screened healthy children and adolescents. Healthy children at the same age may have as much as a 50% differences in total brain volume, further highlighting the need to be cautious regarding functional implications of absolute brain sizes.

Cerebellum

Cerebellum volume peaks about 2 years later than cerebral volume and is the only structure we have quantified that remains significantly larger in males after covarying for total cerebral volume [7].

The cerebellum has traditionally been associated with balance and motor control. However a converging body of evidence from electroencephalography (EEG) studies [8], fMRI studies [9], studies in subjects with vascular and degenerative cerebellar disease [10,11], and histologic studies demonstrating cerebellar connections to dorsolateral prefrontal cortex, the medial frontal cortex, and the parietal and superior temporal areas [12,13] clearly establish the cerebellum's role in many higher cognitive functions. Consistent with the extended maturation of the cerebellum, these cerebellar-subserved higher cognitive functions continue to improve during childhood and adolescence.

Ventricles

Lateral ventricular volume increased robustly with age in the CPB sample of healthy children and adolescents (Figure 1d). This is in agreement with previous reports of greater ventricular volume in adults versus children [4], and is noteworthy because increased ventricular volumes are associated with a broad range of neuropsychiatric conditions. That ventricular volume is highly variable [14] and increases in healthy pediatric development informs interpretation of ventricular volume changes in patient populations.

White Matter

Whether a voxel is classified as gray matter (GM) or white matter (WM) depends largely on the amount of myelinated axons. The MRI signal intensities of nonfluid brain matter voxels generally fall into two bell-shaped distributions; however there is overlap between the distributions, so the exact amount of myelin necessary for classification as WM is somewhat arbitrary and varies slightly depending on different algorithms. Myelination is the wrapping of oligodendrocytes around axons, which acts as an electrical insulator and increases the speed of neuronal signal transmission. An important feature of myelination that has only recently been appreciated is that it does not simply maximize speed of transmission but modulates the timing and synchrony of neuronal firing patterns that convey meaning in the brain [15].

Consistent with previous reports [1,16–21], WM volumes increased throughout childhood and adolescence in the CPB sample (Figure 1c). The rate of increase is age

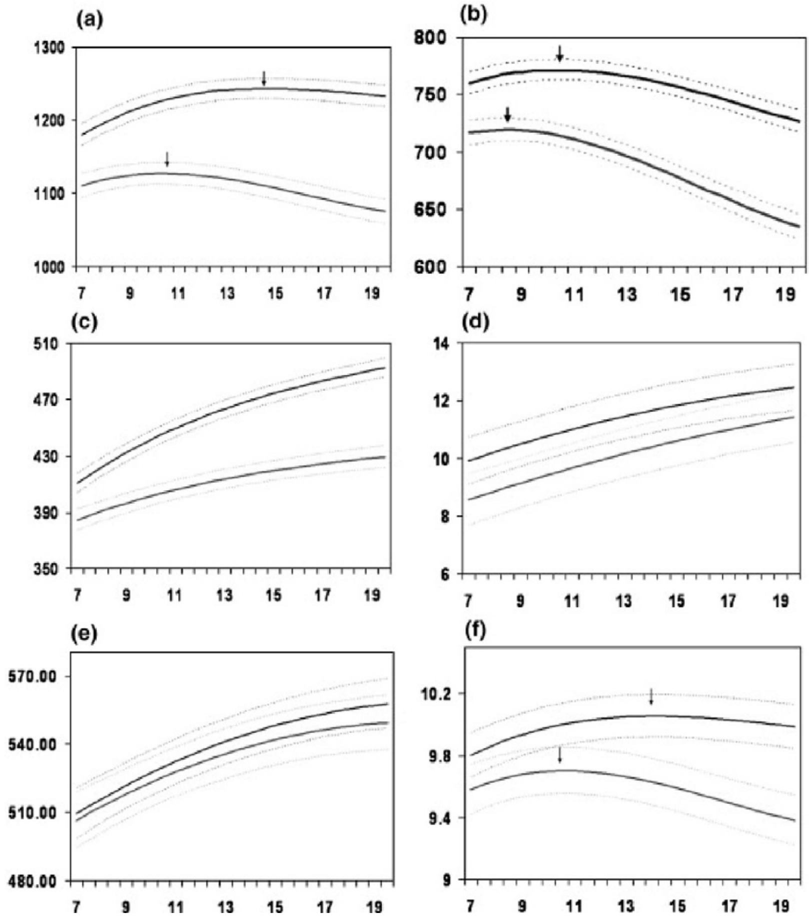

Figure 1. Mean volume by age in years for males (N = 475 scans) and females (N = 354 scans). Middle lines in each set of three lines represent mean values; upper and lower lines represent upper and lower limits of 95% confidence intervals. Arrows indicate point of peak volume. All curves differed significantly between males and females in height and shape with the exception of lateral ventricles, in which only height was different, and mid-sagittal area of the corpus callosum, in which neither height nor shape was different. (a) Total brain volume, (b) gray matter volume, (c) white matter volume, (d) lateral ventricle volume, (e) mid-sagittal area of the corpus callosum, and (f) caudate volume.

dependent [18] and can increase by as much as 50% in a 2-year period in small regions of interest [22]; but at the lobar level (frontal, temporal, and parietal lobes), developmental WM trajectories are similar.

The corpus callosum (CC) is the most prominent WM structure, and consists of approximately 200 million axons connecting homologous areas of the left and right cerebral hemispheres. The functions of the CC can generally be thought of as integrating the activities of the left and right cerebral hemispheres, including functions related to the unification of sensory fields [23,24], memory storage and retrieval [25], attention and arousal [26], and enhancement of language and auditory functions [27]. In agreement with several studies that have indicated increasing CC size during adolescence [22,28–31], total midsagittal CC area increased robustly from ages 4–20 years in the CPB sample (Figure 1e).

The growing interest in exploring neural circuitry has encouraged the development of newer MR techniques, such as DTI and MT, which allow characterization of the microstructure of WM and the direction of axons. DTI studies show decreases of overall diffusion and increases in anisotropy (a measure of the directionality or nonrandomness of the diffusion) during typical child and adolescent development [32]. High anisotropy reflects coherently bundled myelinated axons and axonal pruning, which allow greater efficiency of neuronal communication [33]. A growing body of literature has shown positive correlations between anisotropy and cognitive performance. Specifically, high anisotropy in the temporal lobe correlates with memory capacity [34], in the frontal lobe with language ability [34], in frontal and occipitoparietal association areas with IQ [35], in temporal and parietal areas with reading ability [36–38], and in frontostriatal areas with the ability to inhibit responses to a visual stimulus [39].

Studies using MT imaging have reported increasing magnetization transfer ratio (MTR) values (which increase with myelination) during childhood and adolescence [40–42], although only an adult study has linked MTR values to cognitive performance [43].

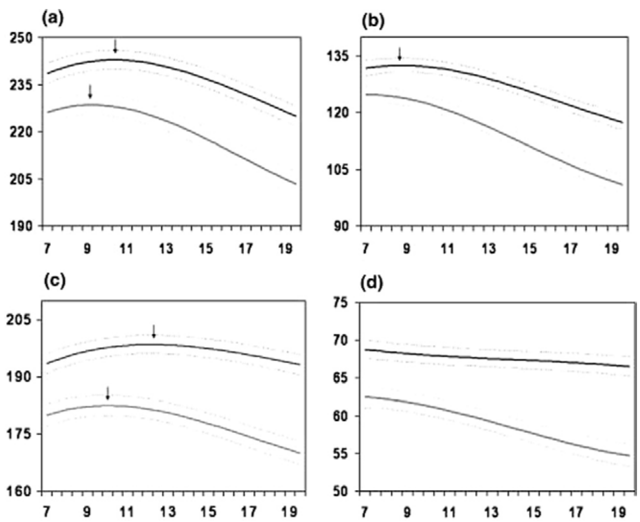

Figure 2. Gray matter subdivisions: (a) frontal lobe, (b) parietal lobe, (c) temporal lobe, and (d) occipital lobe.

Gray Matter

Unlike WM increases during childhood and adolescence, GM trajectories follow an inverted U-shaped path (Figure 1b). This decoupling of GM and WM developmental curves belies the inseparable connection among neurons, glial cells, and myelin, which are fellow components in neural circuits and are bound by lifelong reciprocal relationships [15].

Cortical GM

The GM volumes peak in the frontal lobes at age 9.5 years in girls and 10.5 years in boys; in the temporal lobes at age 10.0 years in girls and 11.0 years in boys; and in the parietal lobes at 7.5 years in girls and 9 years in boys (Figure 2).

At the voxel level, GM densities are not uniform within a given lobe [44]. (An animation of cortical GM changes from ages 4–20 years at the voxel level derived from scans of 13 subjects who had each undergone scanning four times at approximately 2-year intervals is available at http://www.nimh.nih.gov/videos/press/prbrainmaturing.mpeg.) The age of peak GM density is earliest in primary sensorimotor areas and latest in higher order association areas that integrate those primary functions such as the dorsolateral prefrontal cortex, inferior parietal, and superior temporal gyrus.

Postmortem studies suggest that part of the GM changes may be related to synaptic proliferation and pruning [45]. The connection between GM volume reductions, EEG changes, and synaptic pruning is also supported by an MRI and quantified EEG study of 138 healthy subjects aged 10–30 years; this study that found curvelinear reductions in frontal and parietal GM were matched by similar curvilinear reductions in the EEG power of the corresponding regions [46]. Because EEG power reflects synaptic activity (as opposed to WM), the temporally linked EEG power and GM changes suggests that the GM volume reductions are accompanied by reductions in the number of synapses. Another consideration is that myelination may change classification of voxels along the interior cortical border from GM to WM, resulting in cortical thinning as assessed by MR volumetrics, but that it would would not necessarily entail changes in synaptic density [20]. Knowledge of the degree to which these and other phenomema may be driving the MR changes has profound implications for interpreting the imaging results. Imaging of nonhuman primates with postmortem validation may help in this regard.

Subcortical GM

Basal Ganglia

The basal ganglia are a collection of subcortical nuclei (caudate, putamen, globus pallidus, subthalamic nucleus, and substantia nigra) that are involved in circuits mediating movement, higher cognitive functions, attention, and affective states. Basal ganglia anomalies have been reported for almost all neuropsychiatric disorders that have been investigated by neuroimaging [47]. Because of the small size and the ambiguity of MR signal contrast of the borders defining the structures, only the caudate, putamen, and globus pallidus are readily quantifiable by MRI, and reliable automated techniques have been established only for the caudate. Like cortical GM, the caudate follows an inverted U-shaped developmental trajectory, peaking at age 10.5 years in girls and 14.0 years in boys (Figure 1f). The shape of the caudate developmental trajectory is more similar to that of frontal and parietal GM than temporal, supporting the notion that brain regions that share extensive connections also share similar developmental courses.

Amygdala and Hippocampus

The temporal lobes, amygdala, and hippocampus are integral players in the arenas of emotion, language, and memory [48]. Human capacity for these functions changes markedly between the ages of 4 and 18 years [49–51], although the relationship between the development of these capacities and morphologic changes in the structures subserving these functions is poorly understood. The amygdala and hippocampus are adjacent brain structures and part of some of the same neural circuits, but they also subserve distinct functions. The amygdala is a key component of circuitry involved in assessing salience, or the importance of environmental stimuli to survival. The hippocampus is involved in memory storage and retrieval. Connections between the amygdala and hippocampus result in enhanced memory for stimuli with high salience [52,53].

Valid quantification of amygdala and hippocampus volumes still requires manual tracing by expert raters and have not been completed for the longitudinal sample. In a previous report of a cross-sectional sample subset of the CPB sample, amygdala volume increased significantly during adolescence only in males and hippocampal volume increased significantly only in females [54]. This pattern of sex-specific maturational volumetric changes is consistent with nonhuman primate study findings, indicating a relatively high number of androgen receptors in the amygdala [55] and a relatively higher number of estrogen receptors in the hippocampus [56].

Summary of sMRI Changes Occurring in the Second Decade

In the typically developing CPB cohort, total cerebral and GM volumes peak during the ages from 10–20 years, whereas WM and ventricular volumes increase. Age of peak size for GM volumes differs, varies by region, and is generally earlier in females than in males.

Influences on Developmental Trajectories of Brain Anatomy During Childhood and Adolescence

Genes and Environment

To discern the relative contributions of genetic and nongenetic influences on trajectories of brain development, we are conducting a longitudinal neuroimaging study of monozygotic (MZ) and dizygotic (DZ) twins. To date we have acquired approximately 600 scans from 90 MZ and 60 DZ twin pairs. Correlation differences between MZ and DZ twins are analyzed with structural equation modeling to estimate the relative contributions to phenotypic variance of additive genetic (A), shared environmental (C), or unique environmental (E) factors [57]. Structural equation modeling is also useful to assess gene–environment interactions and other epistatic phenomena that challenge conventional interpretation of twin data.

For most brain morphometric measures, additive genetic effects (i.e., "heritability") are high and shared environmental effects are low [58]. Additive genetic effects for total cerebral and lobar volumes (including GM and WM subcompartments) ranged from 0.77–0.88; for the caudate, 0.80; and for the corpus callosum, 0.85. The cerebellum has a distinctive heritability profile with an additive genetic effect of only 0.49, although wide confidence intervals merit cautious interpretation. Highly heritable brain morphometric measures provide biologic markers for inherited traits, and may serve as targets for genetic linkage and association studies [59].

Multivariate analyses allow assessment of the degree to which the same genetic or environmental factors contribute to multiple neuroanatomic structures. Like the univariate variables, these interstructure correlations can be parceled into relationships of either genetic or environmental origin. This knowledge is vitally important for interpretation of most of the twin data, including understanding the impact of genes that may affect distributed neural networks, as well as interventions that may have global brain impacts. Shared effects account for more of the variance than structure specific effects, with a single genetic factor accounting for 60% of variability in cortical thickness [60]. Six factors account for 58% of the remaining variance, with five groups of structures strongly influenced by the same underlying genetic factors. These findings are consistent with the radial unit hypothesis of neocortical expansion proposed by Rakic [61] and with hypotheses that global, genetically mediated differences in cell division were the driving force behind interspecies differences in total brain volume [62–64]. Expanding the entire brain when only specific functions might be selected for is metabolically costly, but the number of mutations required to affect cell division would be far less than that required to completely change cerebral organization.

Age-related changes in heritability may be linked to the timing of gene expression and related to the age of onset of disorders. In general, heritability increases with age for WM and decreases for GM volumes [58], whereas heritability increases for cortical thickness in regions within the frontal cortex, parietal, and temporal lobes [65]. Knowledge of when certain brain structures are particularly sensitive to genetic or environmental influences during development could have important educational and/or therapeutic implications.

Male/Female Differences

Given that nearly all neuropsychiatric disorders have different prevalence, age of onset, and symptomatology between males and females, sex differences in typical developmental brain trajectories are highly relevant for studies of pathology. Robust sex differences in developmental trajectories were noted for nearly all structures, with GM volume peaks generally occurring 1–3 years earlier in females [1]. In our pediatric sample, brain size differences are not accounted for by differences in height or body size. To assess the relative contributions of sex chromosomes and hormones, our group is studying subjects with anomalous sex chromosome variations (e.g., XXY, XXX, XXXY, XYY) [66], as well as subjects with anomalous hormone levels (e.g., Congenital Adrenal Hyperplasia, Familial Male Precocious Puberty, Cushing syndrome) [67,68].

Specific Genes

As with any quantifiable behavioral or physical parameter, individuals can be categorized into groups based on genotype. Brain images of individuals in the different genotype groups can then be averaged and compared statistically. In adult populations, one of the most frequently studied genes has been apolipoprotein E (apoE), which modulates risk for Alzheimer's disease. Carriers of the $\epsilon 4$ allele of apoE have increased risk, whereas carriers of the $\epsilon 2$ allele are possibly at decreased risk. To explore whether apoE alleles have distinct neuroanatomic signatures identifiable in childhood and adolescence, we examined 529 scans from 239 healthy subjects aged 4–20 years [69]. Although there were no significant IQ–genotype interactions, there was a stepwise effect on cortical thickness in the entorhinal and right hippocamapal regions, with the ϵ4 group exhibiting the thinnest, the ϵ3 homozygotes in the middle range, and the ϵ2 group the thickest. These data suggest that pediatric assessments might one day be informative for adult-onset disorders.

Discussion

Three themes emerge from the cumulative neuroimaging research of adolescents, each buttressed by behavioral, EEG, and postmortem studies.

The first is an increase in associative cognitive activity as distributed brain modules become more and more integrated [70]. This increased connectivity is reflected by the WM changes, with fMRI studies suggesting more extensive neural networks, and by increased EEG coherence (reviewed in [71]). If we consider a literary/linguistic metaphor, maturation would not be the addition of new letters but of combining earlier formed letters into words, and then words into sentences, and then sentences into paragraphs.

The second is a general pattern of childhood peaks followed by adolescent declines. This pattern is found not only for GM volumes but for the number of synapses [72–74], glucose use [75], EEG power [76], and neurotransmitter receptor densities [77]. The powerful process of overproduction followed by selective/competitive elimination that shapes the developing nervous system *in utero* seems to continue to refine the brain throughout adolescent development.

The third theme is a changing balance between competing neuronal networks as different cognitive and emotional systems mature at different rates. Many of the cognitive and behavioral changes taking place during adolescence may be understood from the perspective of increased "executive functioning," a term encompassing a broad array of abilities, including attention, response inhibition, regulation of emotion, organization, and long-range planning. These abilities are thought to rely heavily on frontal lobe circuitry that, as indicated above, is relatively late maturing. In addition to the sMRI studies, fMRI consistently shows an increasing proportion of frontal versus striatal or limbic activity from childhood to adulthood for a variety of cognitive tasks [78]. Some changes in limbic reward and motivational systems seem to be associated with the onset puberty, whereas other changes occur earlier or well after the advent of puberty. For example, in an fMRI study of 37 subjects aged 7–29 years that assessed response to rewards, adolescent nucleus accumbens response was equivalent to that in adults, but adolescent orbitofrontal activity was similar to that in children [79].

Elucidating the relationship between neuroimaging findings and behavior is an area of active investigation. Because behaviors emanate from the integrated activity of distributed networks, demonstrating straight-forward relationships between the size of a given brain structure and a particular behavior or ability has been elusive. An important consideration in linking form and function in the brain is that differences in the trajectories of development may in some cases be more informative than the final adult differences. For instance, in our longitudinal study looking at the relationship between cortical thickness and IQ differences in age by cortical thickness, developmental curves were more predictive of IQ than differences in cortical thickness at age 20 years [80].

A target for future investigations is puberty-specific versus puberty-independent changes in brain development. In the CPB sample, we assessed Tanner stage by self-report but did not quantify hormone levels. Studies specifically designed to address this issue, including more precise measures of puberty and comparison of performance in pre- and postpubertal individuals of the same age may help to address this question.

The diagnostic utility of neuroimaging in psychiatry has been the subject of much debate. Although group neuroimaging differences have been reported for nearly all neuropsychiatric disorders, the large overlap of values between clinical and control populations precludes routine application for individuals, except to rule out possible central nervous system insults such as tumors, intracranial bleeds, or congenital anomalies as etiologies for the symptoms. There is no identified "lesion" common to all, or even most, children with the most frequently studied disorders of autism, attention-deficit/hyperactivity disorder, childhood-onset schizophrenia, dyslexia, fragile X, juvenile onset bipolar disorder, post-traumatic stress disorder, Sydenham's chorea, or Tourette's syndrome. The more immediate utility of neuroimaging may be to provide endophenotypes, biologic markers that are intermediate between genes and behavior. Neuroimaging endophenotypes have the potential to define biologically meaningful subtypes of disorders that may respond to different interventions.

Future neuroimaging studies are likely to increasingly combine multiple imaging modalities in the same individuals, such as structural MRI, fMRI, diffusion tensor imaging, magnetization transfer imaging, EEG, and MEG, which will synergistically enhance our ability to interpret the signals for each of the modalities. Being able to simultaneously examine interindividual variation from cellular to macroscopic levels will be instrumental in bridging gaps among genes, the brain, and behavior. A related future direction may be an increase in postmortem studies of animals that have undergone neuroimaging. This would help to clarify the nature of changes driving the MRI findings, such as discerning the degree to which cortical GM changes, as detected with MRI, are related to arborization or pruning of neurons, or to encroachment of WM on the inner cortical border. Another important direction for future neuroimaging studies will be increased integration with social and educational science, which have remained relatively separate despite the shared goal of guiding individuals through the adolescent years safely and optimally prepared for the adult world.

Adolescence is a time of substantial neurobiologic and behavioral change, but the teen brain is not a broken or defective adult brain. The adaptive potential of the overproduction/selective elimination process, increased connectivity and integration of disparate brain functions, changing reward systems and frontal/limbic balance, and the accompanying behaviors of separation from family of origin, increased risk taking, and increased sensation seeking have been highly adaptive in our past and may be so in our future. These changes and the enormous plasticity of the teen brain make adolescence a time of great risk and great opportunity.

Addendum: Technical Aspects, Analysis, and Modalities of Imaging

The term *magnetic resonance imaging* (MRI), if not specifically qualified as a different type, usually refers to the technique that yields different signal intensities for different tissue types (i.e., white matter [WM], gray matter [GM], or cerebrospinal fluid [CSF]). It is sometimes referred to as structural MRI (sMRI) or anatomic MRI to distinguish it from the more recent variants, such as diffusion tensor imaging (DTI), magnetization transfer (MT), or functional MRI (fMRI).

The DTI technique assesses how free water is to diffuse in any direction and provides information about the directionality of WM tracts [32]. The MT imaging technique assesses the ratio of the number of protons bound to macromolecules to the number of unbound protons [81]. This ratio provides a characterization of the microstructure of brain tissue that is different from that provided by sMRI or DTI. Functional MRI (fMRI) capitalizes on the different magnetic properties of oxygenated versus deoxygenated hemoglobin to localize areas of the brain that have increased blood flow during a given task, presumably as a result of neuronal activity triggering greater metabolic need. All of these types of MRI can be performed on the same machine using different software.

An overarching goal of image analysis is to characterize the tissue properties of discrete brain units and to discern a one-to-one correspondence between the unit in one brain image to the unit in another brain image, either from a different person or from the same person at a different time. Discerning one-to-one correspondence between brains is challenging because of the high variation in structural and functional localization. Striving to optimize valid correspondence remains one of the most active areas of image analysis research. The smallest units of MRI pictures are called pixels (or picture elements) and their three-dimensional counterparts voxels (volume elements). Each voxel is assigned a single value based on the average magnetic properties of the tissue in that box. Computer algorithms that combine information about the intensity of the voxel with atlases that inform the probability of tissue type based on the voxel's location in the brain to classify tissue as GM, WM, or CSF are commonly used in sMRI analyses [82].

The size of the voxel can vary depending on magnet strength, and reductions in voxel size can usually be purchased with the currency of time. Most of the literature is from scans producing voxels of 1–3 ml. It is worth noting that even a 1-ml voxel may contain millions of neurons and trillions of synaptic connections, which confers substantial—but often unheeded—implications for interpretation. Also, the single value for a given voxel arises from the average of its more microscopic constituents, and two voxels with the same value may not have identical constituents. In general, voxels classified as WM are thought to consist mostly of myelinated axons, and voxels of solid brain tissue without enough myelin are classified as GM. An electron microscope analysis of a single GM voxel from an adult mouse comprised 29.3% axons, 30.2% dendrites, 12.06% dendritic spines, 9.5% glia, 13.8% cell bodies and blood vessels, and 5.2% extracellular space [83]. However the specific composition may be slightly different in human beings and may vary by age and region. In some voxels, a modest increase in myelin may switch the voxel designation from GM to WM.

Despite these interpretation challenges, MRI's combination of safety, diversity of output parameters (e.g., anatomy, physiology, tissue composition, directionality of WM), and widespread accessibility has unleashed unprecedented insight into the living, growing brain.

A limitation of fMRI is that it relies on changes in blood flow that take place on the scale of several seconds. Modalities such as electroencephalography (EEG) and magnetoencephalography (MEG) have less spatial resolution but provide better temporal resolution by capturing electrical changes at a scale of milliseconds, and provide important complementary information to our understanding of brain development.

The EEG technique measures brain electrical activity thought to be generated largely by ion flow during synaptic activity. A large body of EEG literature has documented stepwise changes in electrical activity throughout the lifespan, including adolescence. Correlations between changes in the coherence of EEG signals from different parts of the brain and the Piagetian capacity for formal operations have been reported [84]. EEG changes in response to various stimuli (i.e., event-related potentials [ERP]) have demonstrated child–adolescent–adult differences that correspond to behavioral changes in capacities [85]. One recent study reports early versus late adolescent ERP differences in the anterior cingulate during detection of error-related conflict [86].

The MEG technique is related to EEG by Maxwell's equations, which eloquently reveal that an electrical current will produce an orthogonally oriented magnetic field. Although both EEG and MEG presumably capture the same phenomena of electromagnetic changes stemming from ions flowing during neural activity, magnetic fields tend to be less distorted by the skull, affording MEG potentially better spatial resolution [87]. Thus far, MEG studies in adolescents have primarily addressed epilepsy; however a growing number of projects are underway to assess language, impulse control, and other cognitive phenomena.

The drawback to these high temporal resolution techniques is that they have poorer spatial resolution than MRI. Currently no single technique offers excellent spatial and temporal resolution of physiologic activity, and comprehensive characterization therefore relies on the integration of information from multiple modalities.

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REVIEW

How Do Adolescents See Their Future? A Review of the Development of Future Orientation and Planning

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Research on how adolescents see their future is reviewed with reference to the three basic processes involved in orientation to the future: motivation, planning, and evaluation. The results suggest that adolescents' goals and interests concern the major developmental tasks of late adolescence and early adulthood, reflecting anticipated life-span development. Such anticipation accounts for a sizeable number of the age, sex, socioeconomic status, and cultural differences in the content and temporal extension of future orientation. The review also showed that the levels of planning and internality concerning the future increase with age. Family context was also found to influence adolescents' future-oriented interests, plans, causal attributions, and affects. Finally, directions for future research are identified.

A major feature of human thinking and acting is orientation toward future events and outcomes. This feature has recently been the subject of increasing attention in psychological theories (Bandura, 1986; Neisser, 1976). However, even though future events motivate everyday behavior over a life-time, thinking and planning for the future are particularly important for young people for several reasons. First, adolescents are faced with a number of normative age-specific tasks (Dittmann-Kohli, 1986; Havighurst, 1948/1974), set by their parents, peers, and teachers, most of which concern expected life-span development and which, therefore, emphasize the importance of thinking about the future. Second, adolescents' future-oriented decisions, such as those related to career, life-style, and future family, crucially influence their later adult life. Third, how adolescents see their future plays an important part in their identity formation, which is often defined in terms of exploration and commitment concerning future-oriented interests (Bosma, 1985; Marcia, 1980). Moreover, adolescent problem behavior, such as delinquency, problems in career choice; and drug abuse, can be expected to be related to how young people see their future.

The majority of studies on future orientation and planning concern late childhood and adolescence which reflects the importance of the future for that age group. Gillispie and Allport (1955) compared students' outlook toward the future in 10 countries in the early 1950s. Since then, dozens of studies have been published on the topic. However, in spite of the vast amount of research in this area, we do not know too much about how adolescents see their future. Reviews have typically concluded that findings are contradictory (e.g., de Volder, 1979). In addition, researchers have suggested that the methods used lack reliability and validity, and are partly responsible for the conflicting results (Perlman, 1976; Ruiz, Reivich, & Krauss, 1967).

My purpose in writing this review is to develop some conception of adolescents' orientation to the future. A theoretical framework is constructed and used to categorize previous research material. The major questions to be answered are the following: What goals and interests do adolescents have in the future? How far into the future does their thinking extend? How good are they at planning their future? How do young people see their chances of influencing expected future events and how do they feel about the future? How do these different aspects of thinking about the future develop during adolescence? And, finally, what are the major factors in the social context that influence this development?

Interestingly, psychological theories have recently focused increasingly on orientation to the future. Bandura (1986, p. 19) stressed forethought capability as one of the basic features of human thinking. Neisser (1976, p. 22) discussed anticipation as one of the main functions of schemata and Oppenheimer (1987, p. 357) underlined future orientation as a major characteristic of goal-directed behavior. Although the time span considered in these theories is rather short, seconds, minutes, and hours, their major ideas also apply to people's everyday thinking extending over longer periods, such as weeks, months, years, even decades. In this review, a new framework based on cognitive psychology, action theory, and life span approach is constructed.

Later on, this framework is used to reorganize and reinterpret the research field of adolescents' future orientation and planning, which is full of conflicting results, as mentioned above.

The framework suggests that orientation to the future is a complex and multistage process that must be conceptualized in relational terms (Nut-tin, 1984) which simultaneously refer to person-related and contextual properties. On this basis, future orientation is described in terms of three major psychological processes, motivation, planning, and evaluation. First, people set goals based on comparison between their motives and values and their expectations concerning the future. Next, they work out how to realize these goals. This is typically done by means of planning and problem solving. Finally, people evaluate the possibility of achieving their goals and actualizing the plans they have constructed. Causal attributions and affects concerning the future are thought to play an important part in this evaluation. Furthermore, the role of knowledge about the expected life span is emphasized, because that provides information about the possible objectives of future-oriented goals, the context in which these goals will be realized, and the extent to which people can control the realization. When adolescents explore future opportunities, set goals, and realize them, they simultaneously develop their own identity.

This forms the basis for the review of studies on adolescents' orientation to the future. In order to give a coherent impression of the research field, only investigations that provide data about the three processes involved in the framework, i.e., content and extension of adolescents' interests and concerns, the level of their planning activity, and the related causal attributions and affects, are considered. In practice, this means that all the studies in which abstract or projective methods are used (see Hoornaert, 1973) and which do not refer to the concrete contents of adolescents' interests and concerns are excluded. Referring to the validity problems in this research field, Perlman (1976) suggested that the content of the thinking should always be considered when orientation to the future is studied.

Once the conceptual framework has been introduced, studies on adolescents' orientation to the future are summarized. The review shows that their thinking about the future reflects their anticipated life-span development in a number of ways: Their goals and interests seem to concern the major developmental tasks they expect to be realized at the end of the second and the beginning of the third decade of life, during late adolescence, and early adulthood. Such expectations are also shown to account for a sizeable number of age, sex, social class, and cultural differences in content and temporal extension of orientation to the future. Furthermore, it will be shown that the level of planning increases until the end of the second decade of life and, in addition, that the level of internality concerning the future increases with age. Following the summary of these studies, a few pertinent research fields, such as identity formation and career decision making, are briefly examined. Finally, research concerning the relationship between orientation to the future and problem behavior is reviewed. Since a theoretical framework is used, this will be introduced first.

CONCEPTUALIZATION OF ORIENTATION TO THE FUTURE

The Psychological Basis

One of the major functions of cognitive schemata is to orient individuals to change in the context of future activities. As suggested by Neisser (1976, p. 22), expectations based on schemata are "the medium by which the past affects the future." The role of expectations in directing human behavior has recently been emphasized by other researchers as well (e.g., Bandura, 1986; Markus & Wurf, 1987).

However, people not only anticipate future events and outcomes, they also give them personal meanings. For example, as people anticipate career changes with age, they also evaluate the changes they would like to be actualized. Similarly, they relate personal standards to these events (Bandura, 1986). Consequently, like schemata, interests and motives also have a reference to future events (Nuttin, 1984).

In addition to being able to anticipate and become interested in the future, people are also able to make judgments about expected future events and behavior outcomes. Furthermore, they often construct complex means-end structures based on the relationships of future events (Cottle & Klineberg, 1974). In all, human ability to anticipate future events, to give them personal meaning, and to operate with them mentally provides a basis for people's orientation to the future.

Three Processes

Orientation to the future is a complex, multidimensional, and multistage phenomenon.

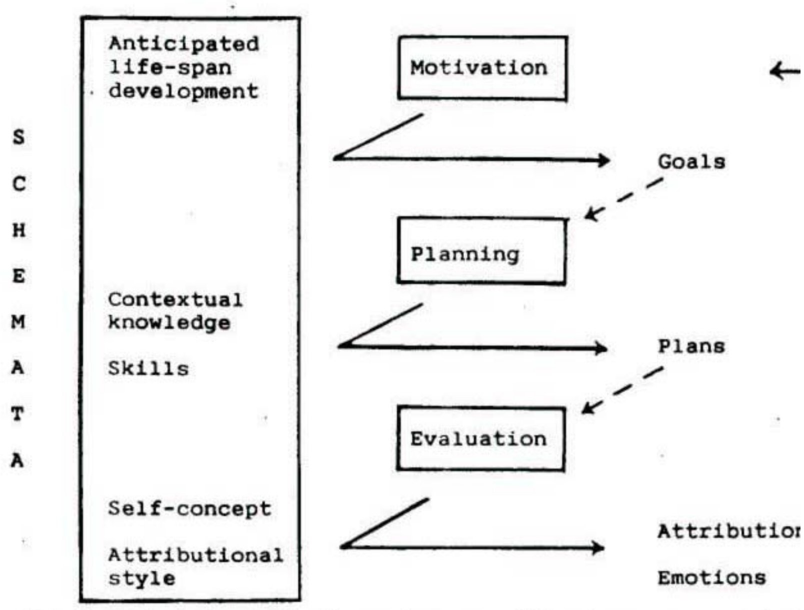

FIG. 1. *Orientation to the future in terms of the three processes invc*

According to the basic ideas of cognitive psychology (Bandura, 1986; Neisser, 1976; Weiner, 1985) and action theory (Leontiev, 1979; Nuttin, 1984), future orientation is described here in terms of three processes, motivation, planning, and evaluation (see also Nurmi, 1989c). In the model, motivation refers to what interests people have in the future. Planning activity, on the other hand, refers to how people plan the realization of their interests in a future context (Nuttin, 1974, 1984). Finally, evaluation concerns the extent to which the interests are expected to be realized.

Future orientation can also be characterized as a three-stage process which interacts with the schemata concerning the future and anticipated self-development. A general overview of these three processes is presented in Fig. 1. First, people set their goals based on comparisons between general motives and values and the knowledge they have about their anticipated life-span development. Second, after people have set their goals, planning activity is required in order to realize them. Knowledge about the expected context of future activities provides a basis for this planning. Finally, opportunities to realize the goals set and plans constructed are evaluated (see also Markus & Wurf, 1987). Following Weiner's (1985) ideas, it is suggested in this investigation that causal attributions and affects concerning the future constitute this third process of orientation. In the next sections, the processes involved in orientation to the future are considered in detail.

Future-oriented motives, interests, and goals. Most of the motives, interests, and goals people have are future-oriented, i.e., they refer to anticipated future events and objectives (Nuttin, 1974, 1984). Since future events and objectives are represented as expectations concerning the future, the knowledge on which these expectations are based plays an important role in the development of future-oriented motivation. In order to set realistic goals, general motives and values have to be compared to knowledge concerning the future. By exploring knowledge related to motives and values, people are able to make their interests more specific. Similarly, Markus and Wurf (1987) recently described goal-setting as comparison between motives or values and the expectations people have about the future.

People's motives, interests, strivings, and goals have recently been characterized as a motivational system consisting of a complex hierarchy, the levels of which are assumed to differ according to the generality and abstractness of the intentions involved (Emmons, 1986; Lazarus & Folk-man, 1987; Leontiev, 1979). The major principle behind this framework is that the higher level motives, values, or strivings are realized via lower level goals, which are further worked out through a number of subgoals. Lower-level goals constitute, in fact, the strategy by which the realization of the higher level motives is planned. On the other hand, higher level personal motives and strivings organize and integrate the lower level goals into hierarchical structures. It is also typical of the goal-hierarchy that higher level goals are less related to specific knowledge concerning the future than lower level goals.

Future-oriented planning. The second major process involved in orientation to the future concerns how people plan the realization of their aims, interests, and goals. Although they may already have realization strategies or procedural knowledge related to their goals, planning and problem-solving are normally required (Cantor & Kihlstrom, 1987; Nut-tin, 1984). In the frameworks of cognitive psychology and action theory, planning has recently been characterized as a process consisting of setting subgoals, constructing plans, and realizing these plans (Hacker, 1985; Nuttin, 1984; Pea & Hawkins, 1987). These three stages can be applied to planning the future as follows.

First, individuals have to construct a representation of both the goal and the future context in which the goal is expected to be realized. Both of these anticipatory representations are based on the knowledge people have about the context of future activities and they provide a basis for the next two phases of planning.

Second, people have to construct a plan, project, or strategy for achieving the goal within the chosen context. Constructing a plan is similar to the process of problem solving: The individual must invent the paths which lead to goal achievement and then decide which of them is most efficient. A comparison of different solutions may be carried out either by thinking or acting. However, since people's interests often extend over years, even decades, action is not possible and, therefore, different action routes have to be evaluated mentally according to how likely it is that they will lead to the achievement of the goal.

The third phase of planning activity is the execution of the plans and strategies constructed. As with general planning, the execution of plans and strategies is also controlled by comparing the representation of the goal and the actual context. In other words, a person taking steps toward a future goal has to check during the course of the action that the original aim is being approached in a systematic way. If not, the plans must be changed (Miller, Galanter, & Pribram, 1960).

Evaluation of the future. Finally, people also have to evaluate the realizability of the goals they set and the plans they construct. It is suggested here that causal attributions and affects concerning future events constitute the third process of orientation to the future, since they are both included in evaluating the possibilities of realizing future-oriented goals and plans. While causal attributions are based on a conscious cognitive evaluation of people's opportunities of controlling their future, affects are responsible for more immediate and also unconscious types of evaluation.

Weiner (1985) recently proposed a model according to which the attribution-emotion process is responsible for evaluating behavior outcomes. The model suggests that the attribution of success and failure to specific

causes is followed by specific emotions. Although it mainly concerns the evaluation of past outcomes, it can also be applied to thinking about the future. For example, the attribution of future success to internal and controllable causes can be expected to be followed by feelings of optimism. In contrast, the attribution of future failure to external and uncontrollable causes should be followed by pessimism. Weiner (1985) himself suggests that the stability dimension of causal attribution determines the hopefulness related to goal attainment: hopefulness is elicited given that a positive outcome is attributed to stable causes.

Brandtst~idter (1984) recently described evaluation as a complex multistage process: first, anticipated developmental changes are assessed in relation to personal values and goals. Then, the expected outcomes are evaluated according to the extent to which they are satisfactory. Next, they are assessed according to how controllable they are and, finally, according to how much control people think they have over this life domain. Brandtst~idter, like Weiner (1985), suggests that each stage of evaluation is followed by a specific affect.

The evaluation process concerns the extent to which people themselves are able to influence and have power over their future. Self-concept therefore plays an important role (Marsh, Cairs, Relich, Barnes, & Debus, 1984): people evaluate their chances of realizing their goals and plans according to their present view of their capabilities (Fig. 1). A few studies also seem to show that people with high self-esteem are more internal in their thinking about the future than those with low self-esteem (Nurmi, 1989d; Plante, 1977).

Future orientation as a system. Orientation to the future is depicted in Fig. 1 as a three-stage process consisting of setting goals, planning their actualization and, finally, evaluating their realizability. However, it must be remembered that these three stages are related in a variety of ways. First, as suggested by Bandura (1986), goals and personal standards provide a basis upon which people evaluate their performance: goal attainments build up a positive self-concept and internal attributional beliefs. Second, the effectiveness of the plans constructed influences the attainment outcome and, therefore, self-evaluation as well. Third, as the arrow -in Fig. 1

indicates, how people evaluate the causes of their success and failure in turn affects the goals and aspirations they set later (Bandura, 1986). Internal attributions concerning a specific future event and related positive affects (Weiner, 1985) are likely to increase interests in this event and the tendency to set high-level related goals.

It is also possible that future-orientation is part of a larger behavioral system that characterizes the whole range of future-oriented everyday behavior. Several researchers have recently discussed strategies by which people respond to the situational demands they face during their life. For example, Cantor and her colleagues (Cantor & Kihlstrom, 1987; Cantor, Norem, Niedenthal, Langston, & Brower, 1987) differentiated two types of achievement strategy among college honors students. The optimistic strategy was characterized by straightforward striving for success based on high expectations derived from positive past experience and a desire to enhance an already strong image of competence. In contrast, typical of students using a pessimistic strategy was setting defensively low expectations, in spite of good past performance, and feeling very anxious and out of control before performance. Jones and Berglas (1978) also described a self-handicapping strategy in the context of underachievement and alcohol use. According to them, the individual using a self-handicapping strategy works to avoid any unequivocal feedback about low ability in important tasks by setting up a protective "attributional environment" before any outcome is known. This is typically built up by acting in a way that provides an excuse for future failure beforehand. In each of these strategies, the goal-setting and planning stages are particularly influenced by the attributional tendencies and self-concept involved in the evaluation of future possibilities.

DEVELOPMENT OF ORIENTATION TO THE FUTURE

The development of future-oriented motivation, planning, and evaluation is a complex, multilevel, and long-lasting process. Three important aspects of it are considered here. First, future orientation develops in cultural and institutional contexts: normative expectations and knowledge concerning the future provide a basis for future-oriented interests and plans, and related causal attributions and affects (Nurmi, 1989a). Second, interests, plans, and beliefs concerning the future are learned in social interaction with other people. Parents, in particular, but also peers, influence how adolescents think about and plan for the future (Kandel & Lesser, 1969). Third, future orientation may well be influenced by other psychological factors, such as cognitive and social development. A detailed discussion about these three issues follows.

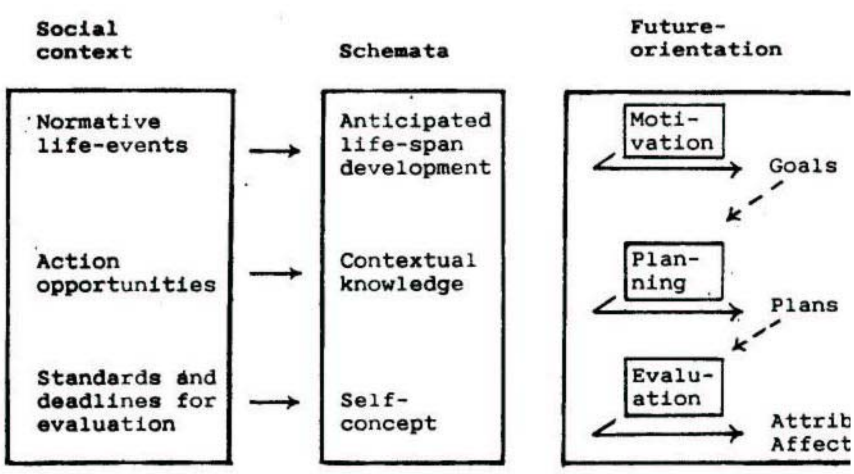

FIG. 2. *A contextual approach to adolescents' orientation to the futur*

Developmental Tasks and Knowledge Concerning Anticipated Life-Span Development

The developmental differences in cultural norms, expectations, rules, and activity patterns have been characterized as developmental tasks (Havighurst, 1948/1974) or normative life-tasks (Cantor & Kihlstrom, 1987; Dittmann-Kohli, 1986). These tasks typically provide (1) knowledge about possible and desired age-specific developmental goals, (2) models for how these goals can be successfully achieved, and (3) normative standards and deadlines for appropriate behavior. Typical developmental tasks of late adolescence include forming sex-role identity, making a

career choice, and acquiring autonomy from parents. During early adulthood, on the other hand, the major developmental tasks are related to marriage, childbearing, work, and life-style (Newman & Newman, 1975).

The development of orientation to the future can be described from a contextual point of view as follows (see Fig. 2). First, normative life-events, related developmental tasks, and their time-table provide a context in which people's future-oriented goals and interests develop. As will be shown in detail later, adolescents' interests typically concern the developmental tasks of that specific age (Nurmi, 1987b, 1989b). Second, life-span-related changes in action opportunities and age-specific models for solving the developmental tasks provide a basis for the development of future-oriented plans and strategies. Finally, standards and deadlines for the successful solution of life-tasks form a basis for the evaluation process involved in orientation to the future. For example, cultural norms involve age-specific standards and deadlines for appropriate ways of solving the developmental task of intimacy, such as knowledge about approved and desirable forms and the age at which dating or living with a member of the opposite sex can begin. It is suggested here that knowledge concerning anticipated life-span development, the context of future activities, and related role models and standards mediate the influence of cultural context.

Developmental tasks and related normative anticipations vary according to a number of factors in addition to age, such as culture, sex, level of education, and socioeconomic status (Dannefer, 1984). Later on, the possibility that the influence of these factors on future-orientation is based on differences in anticipated life-span development is discussed.

Development of Future Orientation in the Family Context

The specific environment in which adolescents live also affects how their thinking about the future develops. Parental influence is at least two-fold. Methods of tutoring children provide the basis for the acquisition of basic skills which are also significant in orientation to the future. Later on, during late childhood and adolescence, parental encouragement, role models, and familial support influence the kind of future-oriented goals and plans, and related causal attributions, children construct.

Learning the basis for goal-setting, planning, and evaluation during childhood. One promising framework for investigating the development of future orientation during childhood is Vygotsky's (1978) idea that psychological functions develop from interpersonal processes to intrapersonal ones (see also Heckhausen, 1987; McGillicuddy-De Lisi, Flaugher, & Sigel, 1987; Sigel, 1982; Wood, Bruner, & Ross, 1976). It is suggested here that the three processes thought to be important in adolescents' orientation to the future may already exist in interaction during which parents tutor their children to solve problems and carry out tasks.

Wood and his colleagues (Wood & Middleton, 1975; Wood et al., 1976) studied children's learning in a tutorial process in which "adults or experts help someone who is less adult or expert." The studies were carried out by observing how mothers interact with their 3- to 5-year-old children in a simple problem-solving situation (Wood & Middleton, 1975). Interestingly, the way Wood et al. (1976) characterize the tutoring process is similar to the model of orientation to the future presented in this review: first the tutor helps the child to keep the goal in his/her mind, then to work out the means of solving the task and, finally, to evaluate the behavior outcomes (see also McGillicuddy-De Lisi et al., 1987).

Parents' tutoring methods may also influence their children's later tendencies to set goals, use certain types of problem-solving and coping strategies and evaluate their own future opportunities. The demands parents make of their children during tutoring may be important in the development of permanent motivational tendencies, such as achievement motivation, the level of goal-setting, and persistence in the realization of goals. What is important is that the level of parental demand in a specific task fits their children's current interests and skills (Wood & Middleton, 1975). Demands that are too high may be followed by feelings of incompetence, whereas too low a level would not optimally increase achievement tendency. Parents' tutoring may also influence children's later tendencies to use specific types of problem-solving and coping strategies when trying to achieve their future-oriented goals. The properties of parental instructional strategies, such as effectiveness, flexibility in different situations, and the level of independence given to the child, can be expected to result in similar tendencies in his or her later planning activity. Finally, the feedback parents give their children about their behavior may be expected to influence how children later evaluate their own behavior. For example, positive and encouraging feedback from parents is likely to increase the internality and optimism of children's beliefs. Later on, these beliefs play an important role in the development of self-concept and attributional styles. Parents have also been shown to be conscious about the influence of their tutoring on their children's planning skills (McGillicuddy, De Lisi et al., 1987).

Research on how parent-child interaction influences adolescents' future orientation is laborious to carry out, because it requires longitudinal studies extending over a 10- to 15-year period. However, a few studies seem to suggest that early mother-infant interaction affects later tendencies related to future orientation. For example, a number of studies has shown that security in mother-infant interaction is predictive of the child's later exploration, autonomy, and problem solving (Ainsworth, 1979; Matas, Arend, & Sroufe, 1978; Sroufe, 1979). On the other hand, Kaman and Moss (1962) found that the extent to which mothers criticized their 1- to 3-year-old daughters correlated positively with the daughters' striving for achievement in adulthood.

The development of orientation to the future during adolescence. The family has been shown to be the most important context during adolescence, although peers and the school environment become increasingly important as young people mature (Jurkovic & Ulrici, 1985). In recent study of the relative importance of parents and peers in adolescent decision making, Wilks (1985) found that young people seek their parents' advice and opinions for longer-term, important, and difficult decisions, whereas friends' opinions and feelings are more important for short-term decisions in less important and less difficult areas.

Parents influence the future orientation of their adolescent children in at least three ways: first, by setting normative standards, they affect interests, values and goals. Adolescents have been shown to have values, beliefs, and goals that are very much like those of their parents (Conger, 1973; Coopersmith, Regan, & Dick, 1975). Thus, the relative importance of work, school, and leisure activities reflected in adolescents' goal-hierarchies can be expected to be learned in the family context. Second, parents serve as models for solving different developmental tasks. For example, the family provides information about how successful marriage is in solving the developmental task related to intimacy. Similarly, planning skills and coping strategies which adolescents apply when they face major developmental tasks may be learned in the family context. Nurmi (1987a) found preliminary evidence that the extent to which mothers planned their own lives correlated positively with the realization level of educational hopes expressed by their children. Third, attributional beliefs concerning the possibility of influencing different domains of life may be learned in family interaction. Nurmi's (1987a) findings suggest that the internality of mothers' beliefs correlates positively with their adolescent children's internality concerning future education.

Peers also influence adolescents' future orientation in a variety of ways. As contemporaries are at the same stage of their life, they provide incentives for thinking about current life-tasks. The peer group also provides individuals with the opportunity of comparing one's own behavior with that of others. Finally, contemporaries influence adolescents' thinking about the future by peer-group pressure.

Cognitive Development and Adolescents' Orientation to the Future

It has been suggested that the evident increase in cognitive skills throughout the years of late childhood and adolescence (Keating, 1980) influences future orientation (e.g., Trommsdorff, 1986) in a variety of ways. The role of formal operations, in particular, has been emphasized. I will now outline how cognitive development influences adolescents' planning for the future.

First, acquiring formal operations during early adolescence enables a person to formulate hypotheses which are contrary to fact and mentally to explore many possible courses of action (Elkind, 1980). This capability is expected to help adolescents set future goals which they are not able to realize immediately and also to construct alternative action plans in their minds (Blasi & Hoeffel, 1974). According to Keating (1980), planning based on anticipatory knowledge, problem definition, and strategy selection seem to be used more frequently by adolescents than children and more frequently by older adolescents than younger ones. Second, acquiring formal operations also increases people's ability to conceptualize their own thoughts which is reflected in the increase of metacognition (Keating, 1980). These metacognitive skills are important, particularly in situations in which people have problems in achieving a specific goal and in which, therefore, the action strategies have to be changed. For example, Pea and Hawkins (1987) showed that 11- to 12-year-olds apply more meta-planning decisions compared with 8- to 9-year-olds (see also Kreitler & Kreitler, 1987).

Third, formal operations enable young people better to conceptualize the thoughts of other people. However, since adolescents cannot differentiate between concerns toward which others' thoughts are directed and their own concerns, this leads to egocentrism and the importance of "imaginary audience" (Elkind, 1967, 1980): adolescents believe that people in general are as obsessed by their behavior as they are themselves. This tendency to be very concerned what others think can be expected to increase the social influence of parents and peers on adolescents' thinking about the future. It has been suggested that egocentrism and the related importance of an imaginary audience diminish by the age of 15 to 16 (El-kind, 1967).

However, studies have shown either low correlations or no relationship at all between cognitive skills and levels of planning for the future. Greene (1986), for example, found no correlation between a Piagetian-type of test measuring formal operations and coherence of future thinking. This may be due to the fact that concrete operational thinking typical of preadolescent-cents may be perfectly adequate for the purpose of hypothesizing about the future and of making plans (Blasi & Hoeffel, 1974). On the other hand, Nurmi (1989b) reported positive but low correlations between intelligence measures and levels of planning, realization, and knowledge about the future. Similarly, a number of studies showed positive but low correlations between intelligence measures and effective planning (Kreitler & Kreitler, 1987; McGillicuddy-De Lisi et al. 1987; Pea & Hawkins, 1987).

In all, the framework introduced here differs in a number of ways from those applied earlier in this research field (reviews: Hoornaert, 1973; Rakowski, 1979; de Voider, 1979). First, future orientation here is put into the context of modern psychological concepts, such as goals, plans, schemata, and causal attributions. It was described in earlier research only in terms of this specific research field which was not associated with other fields of psychology (Hoornaert, 1973; de Voider, 1979). The application of modern psychological theory facilitates the comparison of research on future orientation with that in other pertinent fields, such as the development of planning skills, identity formation, and career decision making. Second, future orientation is described here as a process which consists of three substages, goal-setting, planning, and evaluation. Earlier research in the field typically described it in terms of intraindividual traits (e.g., Agarwal & Tripathi, 1980; Rappaport, Enrich, & Wilson, 1985); how these traits might be interrelated has not been further discussed (Hoornaert, 1973; de Voider, 1979). In contrast, the process approach applied here provides an analytical tool to promote the understanding of the relationships between the different substages involved through the analysis of their role in future-oriented behavior. Third, it is emphasized that life-span-related changes in normative expectations influence the development of adolescents' future orientation. It is suggested that there are changes not only in orientation to the future, but also in the context in which it develops, as adolescents grow older. Although the importance of expectations concerning life-span development has also been discussed earlier (Lessing, 1972; Trommsdorff, 1986), a systematic effort was made here, for the first time, to describe their influence on future orientation. Finally, the development of orientation to the future is characterized as a transactional process influenced by normative parental expectations, tutoring, role models, and emotional support during childhood and adolescence. Although the role of social context has also been discussed earlier (Trommsdorff, 1983, 1986), no similar description of the developmental processes has been published.

The review of research on adolescents' future orientation which follows is based on this theoretical approach. First, however, I would like to say a few words about the methods applied in the field.

METHODS USED IN THE RESEARCH FIELD

Since orientation to the future is described here in terms of motivation, planning activity, and evaluation, only studies that provide information about these three processes are included in the overview of methods and the subsequent review of earlier studies. More specifically, only studies concerning the (1) content and temporal extension of future-oriented interests and goals, (2) related levels of knowledge, planning, realization and, finally, (3) affects and causal attributions concerning them are discussed. Other types of methods, such as abstract or projective measures, which have also been used in the research field, are not discussed here (reviews: Hoornaert, 1973; de Voider, 1979). The major reason for excluding such studies from the review is that they do not provide data about the processes involved in the model presented.

Future-oriented motives, interests, and goals have typically been studied by asking people what kind of hopes and fears (Nurmi, 1987b; Trommsdorff, Burger, & Fuchsle, 1982) or expectations (Mehta, Rohila, Sundberg, & Tyler, 1972) they have concerning the future. Then, the content of these hopes, fears, and expectations has been analyzed by classifying them according to the topics they concern. Although the content categories used vary from one study to another, the most frequently occurring ones include future occupation/profession, education/schooling, leisure activities, family/marriage, property, and self-actualization (e.g., Mehta et al., 1972; Trommsdorff et al., 1982).

People's interests also vary according to how far into the future they expect them to be realized. This dimension has been characterized as temporal extension, time-span, or protension of thinking about the future (Poole & Cooney, 1987). Temporal extension was investigated in the studies reviewed by asking participants to list their hopes or expectations concerning the future and then to estimate the time by which they expect these hopes and aims to be realized (e.g., Wallace & Rabin, 1960; Trommsdorff et al., 1982). Temporal extension is then scored either (a) by the age of the subject at the moment of the realization of the hope or (b) in years from the time of the study to the point of time the hope is expected to be realized.

Studies concerning planning activity are scarce. In a few, however, levels of planning and realization and coherence concerning the future are measured. Verstraeten (1980), for example, asked students to produce goals and aims using Nuttin's (1985) Motivational Inventory. Then, the subjects were requested to write down how they were going to accomplish each goal. In addition, they were asked to write down whether they had done anything concrete to achieve the goal. On the basis of the answers, the levels of planning activity and realization were analyzed. Similarly, Nurmi (1987b, 1989b) analyzed the complexity of future-oriented plans, their level of realization, and the level of knowledge involved as they were verbally reported in the interview. Studies based on a self-rated level of planning have also been carried out (Cameron, Desai, Bahador, & Dremel, 1977-78).

According to the model presented, evaluation of the future is based on causal attributions and affects. Causal attributions concerning the future have usually been measured by asking subjects to rate the extent to which they believe they can exert control over the realization of their hopes and fears (Nurmi, 1987b; Trommsdorff et al., 1982). Other dimensions of causal attribution, e.g., their stability and globality (Weiner, 1985), have not featured in the studies.

On the other hand, affects concerning the future have been measured using a variety of methods. For example, optimism has been investigated by analyzing the content of written essays (Mrnks, 1968). Affects have also been measured by asking people to rate the likelihood of the realization of their hopes, indicating optimism (Trommsdorff et al., 1982), or by asking them to evaluate their overall hopefulness concerning the future (Nurmi, 1987b). Furthermore, the relative proportion of future events rated as pleasant compared with those rated as unpleasant has been used -as an index of optimism concerning the future (Poole & Cooney, 1987). There are a number of problems with the methods, particularly considering the conceptualization introduced here. First, they yield relatively basic information about orientation to the future. For example, in none of the studies reviewed was future orientation investigated as a multistage process. Neither has the hierarchical structure of future-oriented interests and life-goals been examined. Second, the methods used vary to a great extent from one study to another, even if only those which provide data about the major concepts of the model introduced here are considered. This lack of standardized methodology makes it difficult to compare the results of various studies. Third, studies on future orientation apply questionnaire and interview methods. However, the extent to which these measures correlate with people's actual behavior in situations which involve future-oriented planning and decision making has not been investigated. Finally, there is also a wide variety of ways of measuring contextual factors. For example, measures of family relationships vary from one study to another.

RESEARCH ON ADOLESCENTS' FUTURE ORIENTATION AND PLANNING

Using the theoretical framework and classification of the methods presented as a basis, research on adolescents' orientation to the future and the factors determining its development will now be summarized. First, the interest adolescents have in the future and how far their thinking extends are analyzed. Then, the development of future-oriented motivation, planning activity, and evaluation is reviewed. Next, the role of developmental context is analyzed by examining the effects of sex, socioeconomic status, and family interaction on adolescents' thinking about the future. The samples, methods, and major results of the studies are summarized in Table 1. Finally, cross-cultural differences in adolescents' future orientation are reviewed.

What Interests in and Concerns about the Future Do Adolescents Have?

Goals and expectations. All the studies concerning the content of hopes, aims, and expectations show that adolescents are most interested in their future occupation and education. M6nks (1968) reported results among Dutch adolescents showing that the most frequent statements were those referring to school and vocation. Similar results were found in a number of studies using different types of method (Gillies, Elmwood, & Hawtin, 1985; Meissner, 1961; Nurmi, 1987b, 1989b; Poole & Cooney, 1987; Seginer, 1988a, 1988b; von Wright & Rauste-von Wright, 1977). Moreover, in contrast to many other contents of thinking about the future, no major cross-cultural differences have been found in interests concerning future occupation and education (Mehta et al., 1972; Solantaus, 1987; Sundberg, Poole, & Tyler, 1983). The next most common topics that adolescents are interested in are future family and marriage, leisure activities, and the material aspects of life (Gillies et al., 1985; Gillispie & Allport, 1955; M6nks, 1968; Nurmi, 1987b, 1989b; Seginer, 1988a, 1988b). However, the results vary to a great extent according to a number of variables such as age, gender, and culture (Gillispie & Allport, 1955; Mehta et al., 1972; Solantaus, 1987; Sundberg et al., 1983). This will be discussed in detail later.

The results suggest that adolescents' goals and interests concern the major developmental tasks (Havighurst, 1948/1974) of late adolescence and early adulthood, such as future education, occupation, family, and the material aspects of their future life. Interestingly, when Dreher and Oerter (1986) asked adolescents directly about their thoughts on developmental tasks, they found that young people, at the ages of 15 and 16, were aware of them and also consciously active in coping with them. As a negation of interests, adolescents are also concerned about the occurrence of events they feel to be threatening. Next, I will examine what studies show about these concerns.

Fears and concerns. Although the content of adolescents' fears and worries varies according to a number of factors, such as age, culture (Solantaus, 1987), and methods used (Nurmi, 1988a), adolescents seem to be concerned about three major topics. First, they have been shown to express a number of worries and concerns related to normative life-tasks, such as getting a job and a good education, and starting a family. For example, the threat of unemployment (Gillies et al.; Goldberg et al., 1985; Solantaus, 1987), school failure (Payne, 1988), and divorce in the future (Rauste-von Wright, 1987) have been shown to be reflected in their thinking. Second, adolescents seem to be concerned about the non-normative events related to their parents and present family. For example, American and Caribbean adolescents have been reported to be concerned about the health of their parents, while Soviet children were more concerned about the possibility of their parents' divorce (Chivian et al., 1985; Goldenring & Doctor, 1984; Payne, 1988). The third class of adolescents' worries concerns societal events, especially the threat of nuclear war, a topic that has recently been the subject of a great deal of research (Goldberg et al., 1985; Goldenring & Doctor, 1984; Nurmi, 1988a; Solantaus, 1987; Solantaus, Rimpel~i, & Taipale, 1984; for a review, see Solantaus, Rimpel~i, & Rahkonen, 1985).

If adolescents' major concerns and worries are compared with their hopes and aims, the results seem to show a polarization of thinking (see also Poole & Cooney, 1987): adolescents are positively interested in topics related to their personal future, such as future occupation, education, and family. On the other hand, many are concerned about global and societal threats, such as nuclear war and unemployment. From this polarization, one interesting issue arises: how do global threats influence adolescents' thinking about their own future? Interestingly, however, when these relationships have been studied, it has been shown that experience of the threat of war does not decrease adolescents' thinking about and planning for their personal future life (Goldberg et al., 1985; Nurmi, 1988a, 1989b).On the contrary, adolescents who experience the threat of war have been found to be more interested in their future family and occupation than other youths (Nurmi, 1988a). These results indicate that, although adolescents are concerned about the global threats which they feel powerless to influence, they are able simultaneously to plan their own future.

TABLE 1

SUMMARY OF STUDIES ON ADOLESCENTS' ORIENTATION TO THE FUTURE

Study	Sample	Age	Method	Independent variables	Dependent variables	Main results
Bentley (1983)	98 Scottish, 106 Swazi	12–25	Questions concerning the future, questionnaire	Sex, culture	Extension (age), content	Boys extended further into the future than girls.
Cameron, Desai, Bahador, & Dremel (1977–78)	1031 Americans	9–65	Expected future events, interview	Age, social class	Planning	14- to 17-year-olds planned their future less compared with 18- to 25-year-olds.
						Subjects from a higher social class claimed that they plan their future more than the lower class subjects.
Cartron-Guerin & Levy (1980)	80 French	12–15	Questionnaire on future family and career	Age, sex	Content, extension	Older adolescents and males projected further into the future.
						Older adolescents and females gave greater importance to their future family.
Freire, Gorman, & Wessman (1980)	54 Americans	7–11	Future expectancies, interview	Social class	Content	Lower class children have expectations related to playing, moving, travelling, whereas higher class children have more expectations related to job, marriage/children, and home.
Gillies, Elmwood,	1797 English	11–16	Hopes & fears	Age, sex	Content	Among future hopes employment,

						More girls than boys hoped for a happy marriage, and more boys than girls desired wealth.
						The most common fear was unemployment. Its proportion also increased with age.
Goldberg et al. (1985)	2000 Americans	13–19	Fears & hopes questionnaire	Age, sex	Content	Among future fears, nuclear war and unemployment were most prominent. Worries about nuclear war decreased with age, while worries about unemployment increased with age.
Goldenring & Doctor (1984)	1000 Americans	11–19	Future worries check list		Content	Among future worries, the death of parents and nuclear war were most prominent.
Greene (1986)	60 Caucasians in the U.S.	15–19	Future events questionnaire	Age, sex	Extension (age), coherence.	Older students extended more into the distant future (by age). No age differences in coherence.
Klineberg (1967)	90 French	10–17	Future events interview	Age, delinquents vs. non-delinquents	Extension (age), coherence	Older adolescents expressed longer extension (in age) compared with younger ones.
						Older adolescents' future orientation was more consistent compared with that of younger ones.
						Maladjusted children extend further into the future compared with normal children, while normal

TABLE 1—*Continued*

Study	Sample	Age	Method	Independent variables	Dependent variables	Main results
Lamm, Schmidt, & Trommsdorff (1976)	100 West Germans	14–16	Hopes & fears questionnaire	Sex, social class	Content, extension (years), internality	Girls voiced more hopes and fears in the private sphere, including family. Boys listed a greater amount of occupational hopes and fears.
						Girls were more external in their future thinking compared with boys.
						Middle-class adolescents voiced more hopes relating to public life and have more extended future orientation than lower-class adolescents.
Lessing (1972)	168 Americans	9–15 girls	Future events questionnaire	Age	Extension (years)	Younger girls have more extended future orientation than older girls.
Levine, Spivack, Fuschillo, & Tavernier (1959)	47 Americans	11–19 delinquent boys	Future events questionnaire	Age	Extension (age)	Older boys placed events farther into the future (by age) than younger boys.
Meissner (1961)	1278 Americans	13–18 boys	Future worries questionnaire	Age	Content	General areas of worry were school, sex, popularities, immorality, and vocational future.
						School topics decreased with age, whereas worries concerning future

Mönks (1968)	1424 Dutch	14–21	Future outlook essay	Sex	Content	Adolescents were most interested in school, vocation, and future family and home.
						Boys were more interested in school and vocation, whereas girls were more concerned about future family and marriage. Boys also have clearer concepts about political and social procedures.
Nurmi (1987b)	148 Finnish	10–19	Hopes and fears interview	Age, sex, social class, family atmosphere	Content, extension (years), planning, knowledge	Hopes relating to occupation, education, and family increased with age.
						Extension of future thinking decreased, whereas the levels of knowledge and planning increased with age.
						Girls had more hopes concerning future family but did not have fewer hopes concerning vocation or education.
						Adolescents from the higher social classes projected further into the future in the vocational domain compared with lower-class adolescents.
						A negative climate in the family is negatively related to future planning among 11-year-olds but

TABLE 1—*Continued*

Study	Sample	Age	Method	Independent variables	Dependent variables	Main results
Nurmi (1989a)	218 Finnish	10–15 (longitud. & cross-sect.)	Hopes and fears interview	Age, sex, time of study	Content, extension, planning, internality, affect	Adolescents were most interested in future education, occupation, family, and property. Hopes concerning education increased, whereas hopes concerning leisure activites decreased with age.
						Both 11- and 15-year-olds extended in their thinking to about the age of 20.
						Levels of planning, realization, and knowledge increased with age.
						Internality and optimism concerning the future increased with age, especially among boys.
O'Rand & Ellis (1974)	80 Americans	17–19 boys	Future events questionnaire	Social class	Extension (age)	Higher class adolescents extended further into the future compared with lower class subjects.
Poole & Cooney (1987)	440 Australians, 162 Singaporeans	14–15	Future events questionnaire	Culture, sex, social class	Content, extension (years), affects	Adolescents most frequently mentioned future work, education, and family.
						Adolescents from high social

						interested in topics related to work than those from lower social class backgrounds.
						Females had shorter extension than males.
Pulkkinen (1984)	154 Finnish	20 Longitudinal study (8–20)	Interview	Sex, family, atmosphere	Content, planning, realism	Girls were more oriented toward future family and more worried about occupation, whereas boys were more oriented toward

TABLE 1—*Continued*

Study	Sample	Age	Method	Independent variables	Dependent variables	Main results
Solantaus (1987)	600 Austrians, 596 British, 665 Finnish	11–15	Hopes & fears questionnaire	Culture, age, sex	Content	Hopes concerning work and employment were most frequent for all national groups.
						Hopes and worries concerning work and employment increased with age. Hopes for a future family increased with age among Finns.
						In all countries, boys expressed more hopes about the material aspects of life and fewer worries about their future family compared with girls.
Trommsdorff & Lamm (1975)	200 girls and boys, 200 males and females	14–16 35–45	Hopes & fears questionnaire	Sex, social class, adolescents vs. adults	Content, extension (years)	Higher-class subjects had more extended future orientation than lower-class subjects.
						Females were more concerned about family-related topics.
Trommsdorff et al. (1978)	48 West Germans	11–15	Hopes & fears questionnaire	Age, parental support	Coherence, externality	15-year-olds structured their hopes related to their future family more precisely than 11- and 13-year-olds.
						15-year-olds expected to have less

						Adolescents experiencing little parental support were less optimistic about their future and also more external in their future thinking. They also showed less extension and differentiation with regard to their economic and occupational future.
						Girls' hopes related to family were more structured than boys', whereas boys' hopes related to material domain were more structured than girls'.
Trommsdorff, Lamm, & Schmidt (1979)	48 West Germans	Longitudinal study (14–16 and 16–18)	Hopes & fears questionnaire	Age, school form	Content, extension (years), externality	Older subjects have more hopes and fears related to occupation and personal growth.
						Boys have more extended future orientation compared with girls, especially in older age groups.
						Low-status subjects voiced more hopes and fears related to occupational domain.
						Low-status subjects after participating in working life were more internal than high-status subjects.
Tyszkowa (1980)	520 Polish	11–15	Expected life situation at	Social class	Planning	Lower-class adolescents planned their vocational and educational

TABLE 1—*Continued*

Study	Sample	Age	Method	Independent variables	Dependent variables	Main results
Verstraeten (1980)	113 Belgians	15–17	Goals & desires questionnaire	Age, sex	Extension (age), realization	Older subjects showed more extended future orientation (by age) than younger subjects. They also show more realization of their goals and lower subjective probability evaluations than younger subjects. More girls than boys have wants concerning their adulthood. Girls also have more elaborated aspirations in the educational domain compared with boys.
Vincent (1965)	48 Americans	14–15	Expected life events interview	Social class	Extension (years)	Children from a high social class looked further into the future compared with low-class children.
Webb & Myers (1974)	160 Americans	9–19	Expected life events questionnaire	Age	Extension (years)	A U-shape relationship between age and extension: the youngest age group has the most extended future orientation, whereas 15-year-olds have the shortest and 18-year-olds the next shortest extension.
von Wright & Rauste-von Wright (1977)	209 Finnish	17–18	Questions concerning the future,	Sex	Content, extension (age)	Boys were interested in more distant events than girls.

How Far into the Future Does Adolescents' Thinking Extend?

One of the most frequently studied dimensions of adolescents' future orientation is how far into the future their goals and expectations extend. The results show that young people, whatever their age and cultural background, extend in their thinking to the end of the second and the beginning of the third decade of life. For example, Sundberg et al. (1983) found that average orientation among American, Indian, and Australian adolescents ranged from 18.3 years of age for Indian girls to 20.4 years of age for Australian girls. Similar results were found by Nurmi (1987b) for Finnish adolescents and by Poole and Cooney (1987) for Australian and Singaporean adolescents. These results are consistent with findings concerning the content of interests and goals, because the developmental tasks they typically concern, such as future occupation, education, and family, are expected to be actualized just at the end of the second and the beginning of the third decade of life.

Nurmi (1987a, 1989b) recently investigated the role of anticipated life events in adolescents' orientation to the future by comparing the mean extensions of future goals according to content. The results showed that adolescents anticipated that their hopes for their future education would be actualized, on average, at the age of 18. l, for leisure activities at the age of 18.5, for occupation/profession at the age of 22.5, for a future family at the age of 25.0, and, finally, for property at the age of 25.2 (Nurmi, 1989b). These results suggest that adolescents' future-oriented goals and interests, and also their time-span, reflect "the cultural prototype" of anticipated life-span development: Young people expect to finish their education first, then to get a job, third to get married, and finally, to build up a material basis for their later life. Interestingly, only few 11- to 15-year-old adolescents expressed hopes which they expected to be realized after the age of 30 (Nurmi, 1989b).

The Development of Future-Oriented Motivation, Planning Activity, and Evaluation

The developmental changes in orientation to the future will now be analyzed separately for motivation, planning activity, and evaluation. Since development measured as age is a complex variable consisting of a whole range of influencing factors, such as physiological maturation, development of cognitive skills, and age-related changes in social context, the mechanisms responsible for the age differences will also be discussed.

Interests, goals, and concerns. Studies based on age-group comparisons show that adolescents become more interested in and concerned about their future occupation (Gillies et al., 1985; Goldberg et al., 1985; Meissner, 1961; Nurmi, 1987b; Solantaus, 1987; Trommsdorff, Lamm, & Schmidt, 1979), education (Nurmi, 1987b) and family (Cartron-Guerin & Levy, 1982; Nurmi, 1987b) with age. Nurmi (1989b) recently found similar results using longitudinal data. He also reported considerable stability of

interest concerning future education and occupation over a 4-year period during early adolescence. On the other hand, Nurmi's results show that adolescents become less interested in leisure activities as they grow older.

In sum, it seems that, as adolescents grow older, they become increasingly interested in developmental tasks concerning future education, occupation, and family. Moreover, young people seem to become interested in the life-tasks of late adolescence (e.g., education) earlier than they do in the tasks of early adulthood (e.g., future occupation and family) (Nurmi, 1989a). However, increasing interest in occupation seems to arise during late childhood: Oppenheimer and Van der Wilk (1987) found that changes in interest from imaginary heroes referring to power and fame to more realistic orientation, including professional goals, take place between the ages of 8 and 11.

Extension of interests. Results concerning development before adolescence (Kreitler & Kreitler, 1987) show that, at the beginning of the second decade of life, children are both interested in and able to think about events touching on the far future. I now intend to investigate how extension of thinking about the future develops after this period, during adolescence. However, in order to find a consistent pattern of results and unlike previous reviews (e.g., de Voider, 1979), the studies will be grouped according to how the extensions were measured.

The first group of studies, measuring extension by age of participants, shows that older adolescents' thinking extends further into their life span compared with that of younger adolescents (Greene, 1986; Klineberg, 1967; Levine, Spivack, Fuschillo, & Tavernier, 1959; Verstraeten, 1980). In contrast, when extension is measured by years from the point of study, the results show that younger adolescents extend further into the future compared with relatively older adolescents (Lessing, 1972; Webb & Mayers, 1974). Nurmi (1987b) even found both tendencies in one study when he investigated orientation to the future among adolescents aged 11 to 18. These results indicate that extension measured by years is longer for younger than for older adolescents and decreases with age as the realization of the developmental tasks or milestone events (Lessing, 1972) approach in time. However, there seems to be a tendency for older adolescents to orient, at least to some extent, toward more distant stages of their life span compared with younger adolescents.

Planning for the future. Recently, a growing number of studies have been carried out on the development of children's planning skills (see Friedman et al., 1987). These studies show, not surprisingly, that planning efficiency increases with age (Kreitler & Kreitler, 1987; Pea & Hawkins, 1987) and that, at least by the age of 10 to 11, children have acquired basic planning skills (Oppenheimer, 1987). However, it seems that planning skills continue to develop after this age up to the early 20s, as shown by

Dreher and Oerter (1987). I will now proceed to examine whether this development is also characteristic of planning for the future.

Most results show that the levels of planning, realization, and cognitive structuring concerning the future increase as adolescents grow older. Verstraeten (1980) studied verbally reported plans among 15- to 17-year-olds and found that realism in thinking about the future measured against the levels of planning and realization of future goals increased with age. Similarly, using both cross-sectional (Nurmi, 1987b) and longitudinal data (Nurmi, 1989b), Nurmi found that 11- to 18-year-old adolescents' levels of knowledge, planning, and realization concerning future goals increased with age. In addition, Cameron et al. (1977-78) found that 14- to 17-year-olds assessed the level of their future planning lower than 18- to 25-year-olds did. Nurmi's (1989b) results, which were based on analysis of the complexity of future-oriented plans in terms of the means-end relationship used, seem to suggest that the development of plans and the level of their realization are more quantitative than qualitative by nature.

Results concerning coherence of thinking about the future are more contradictory: While Klineberg (1967), in a study of 10- to 17-year-old adolescents, found that coherence of future orientation increased with age, Greene (1986) found no age effect among adolescents aged 15 to 19 using a similar coherence measure. Coherence was measured as consistency between the arrangement of future events according to the time of their realization in two tasks, and it is possible that it taps a different type of processing than the planning measures reviewed above.

The fact that levels of planning, realization, and knowledge concerning the future increase with age may be due either to the development of cognitive skills or to contextual changes in the planning situation during adolescence. However, when the influence of cognitive skills on planning for the future has been studied, the results show either low correlations (Nurmi, 1989b) or no relationships at all (Greene, 1986) between the levels of cognitive skills and planning activity. Another possible reason why levels of planning and realization increase with age concerns the changes in the planning context (Cantor & Kihlstrom, 1987). In this case, planning for the future may become more meaningful and also more encouraged by parents and teachers as adolescents grow older. For example, adolescents are usually encouraged to plan their education just before the end of secondary school at the age of 14 to 15. Similar important periods of contextual changes in life-planning may be identified for occupation and future family as well. However, research on the extent to which the development of life-planning is determined by contextual changes at different stages of adolescence has not been carded out.

Causal attributions and affects concerning the future. Only a few studies concerning the development of causal attributions and affects related

to the future have been published. Nurmi's (1989b) results showed that preadolescents' beliefs about the future become more internal with age. He further suggested that the increase in internality may reflect adolescents' growing opportunities for controlling their life. In contrast to Nurmi’s results, however, Trommsdorff, Burger, Fuchsle, and Lamm (1978) reported decreasing internality during early adolescence. Nurmi (1989b) also reported sex differences in the development of optimism. His results showed that the increase in optimism applied more to boys, whereas girls showed a tendency to become more pessimistic with age. These results are similar to those reviewed by Petersen (1988) showing that girls, in contrast to boys, appear to display increased depressive affect over the adolescent period.

How Does Social Context Influence Adolescents' Future-Oriented Motivation, Planning, and Evaluation?

In interaction with their parents, peers, and teachers, children learn normative expectations concerning life-span development, related role models, and behavioral standards. However, normative life-span development and related cultural knowledge differ according to a number of factors, such as sex, socioeconomic status, and the subculture in which the children are living (Dannefer, 1984). In addition, the skills, coping strategies, and attributional styles, which children apply when coping with major life-tasks and which they learn in their home are also likely to vary along similar lines. To investigate how social context influences future-oriented motivation, planning, and evaluation, I will now turn to studies concerning the effects of sex, socioeconomic status, and family interaction on adolescents' thinking about the future.

Sex roles. Culture-bound expectations concerning life-span development vary to large extent according to sex. Traditionally, males participate more actively in education and working life, whereas females are more involved in family and domestic activities. Not surprisingly, studies on sex differences in adolescents' orientation to the future show that boys tend to be more interested in the material aspects of life, whereas girls are more oriented toward their future family. Gillespie and Allport (1955) found in their extensive cross-cultural study that more girls than boys hoped for a happy marriage and more boys than gifts desired wealth. Similar results have been found in a number of studies (Cartron-Guerin & Levy, 1982; Gillies et al., 1985; Pulkkinen, 1984; Solantaus, 1987). Furthermore, Lueptow (1984) found that male and female responses to the life goal items were stereotypic. Girls value religion, making contribution to society, and family, while boys stress showing others, luxury, status, and success. However, there was no sex difference in the importance of occupation as a life goal. Oppenheimer and van der Wilk (1987) reported

results showing a typical sex-related pattern in children's interests as early as the age of 5, suggesting that sex-typical thinking develops in early childhood. Interestingly, Trommsdorff et al. (1978) found that girls' hopes for a future family were more structured than boys', while boys' hopes in material domains were more structured than those of girls. This results suggests that sex roles influence not only adolescents' interests but also their knowledge about these topics.

Results concerning the influence of sex on how far into the future adolescents' thinking extends are contradictory. A number of studies show that boys extend further into the future compared with girls (Bentley, 1983; Cartron-Guerin & Levy, 1982; Poole & Cooney, 1987; Trommsdorff et al., 1979; von Wright & Rauste-von Wright, 1977), whereas some other studies (Greene, 1986; Nurmi, 1987b; Verstraeten, 1980) found no sex differences in extension. Results showing that boys' thinking extends further into the future compared with girls' thinking may be due to the sex differences in the content of adolescents' interests, as was shown before: girls' shorter time span may be due to the fact that they have more female-type interests, such as getting married and having a lower level of education, where the realization time is objectively situated in the more immediate future compared with the contents which interest the boys, i.e., occupation and the material aspects of life. Furthermore, Lamm, Schmidt, and Trommsdorff (1976) found that, although girls' future orientation was directed toward the attainment of occupational goals, their thinking concerned goals that extended rather less far into the future compared with boys.

In all, boys and girls were shown to differ in particular according to the content of their interests and related temporal extension. This may be due to the differences in normative life-span development between males and females. However, some cross-cultural variation in the influence of sex on adolescents' thinking about the future has been found. This will be discussed in detail later.

Socioeconomic status, The few studies carded out on the influence of socioeconomic status on the content of adolescents' interests show that future working life is more emphasized in the thinking of lower-class adolescents, whereas middle-class adolescents tend to be more interested in education, career, and leisure activities (Poole & Cooney, 1987; Trommsdorff et al., 1979). Moreover, Lamm et al. (1976) found that middle-class adolescents voiced more hopes relating to public life than personal life compared with lower-class adolescents.

A number of studies also show that adolescents with a relatively high socioeconomic status extend further into the future compared with young people from a low socioeconomic background (Mehta et al., 1972; Nurmi, 1987b; O'Rand & Ellis, 1974; Trommsdorff & Lamm, 1975; Vincent,

). Nurmi (1987b) found this to be true especially for hopes concerning vocational interests. One possible explanation for these results is that, on average, in the higher social classes, the principal developmental tasks are anticipated to be actualized at a later stage of life than in the lower classes (Nurmi, 1987b). Boocock (1978) reported results showing that American adolescents from high status homes make major life-course transitions at a later age than their low-status peers. As stated by Trommsdorff (1983, 1986), the shorter extension of lower-class adolescents reflects the realistic appraisal of their expected life-span rather than individual deficiencies in thinking about the future. Most studies on the level of planning for the future show that adolescents with a high socioeconomic status tend to plan their future more than youths with a relatively low socioeconomic position (Cameron et al., 1977-78; Trommsdorff et al., 1978; Tyszkowa, 1980).

In all, the results suggest that adolescents' socioeconomic status influences their interests and related temporal extension, reflecting differences in anticipated life-span development.

Family context. Parent-child interaction was expected to play an important part in the development of adolescents' orientation to the future: first, by setting normative standards, parents influence the development of their children's interests, values, and goals. Second, parents may serve as models for solving different developmental tasks. Third, parental support may provide a basis for adolescents' internal and optimistic attitudes toward the future. For example, Dreher and Oerter (1986) found that adolescents frequently mentioned support from their parents as helpful when they were asked about the factors influencing their ability to cope with developmental tasks:

Results in the field show that family context influences adolescents' future-oriented interests and goals in a variety of ways: for example, a low level of parental control seems to encourage them to become interested in major developmental tasks, such as future education (Nurmi, 1989d), at a relatively early age. This may be due to the fact that a relatively low level of parental control increases preadolescents' independence, which is further reflected in their earlier involvement in the planning of their future education and career compared with their contemporaries. Moreover, parents' educational goals have been Shown to be associated with those of adolescents (Kandel & Lesser, 1969). The family also seems to provide a model for how adolescents plan to solve different developmental tasks, in particular intimacy: A few studies seem to show that positive family interaction (Nurmi, 1989d) and the marital happiness of parents (Niemi, 1988) encourage adolescents actively to plan for their own future marriage and family. Parental support has been shown to increase adolescents' level of planning activity in occupational and educational domains

(Nurmi, 1987b; Trommsdorff et al., 1978), and to increase optimism and internality concerning the future (Nurmi, 1989d; Pulkkinen, 1984; Trommsdorff et al., 1978). In all, these results seem to provide some evidence for the developmental model presented earlier.

Recently, Nurmi (1988b, 1989d) also reported developmental changes in the effects of parent-child interaction on adolescents' thinking about the future. His research revealed that parental control plays an important role at the age of 11, decreasing the level of optimism, whereas the level of family discussion is important at the age of 15, increasing the level of optimism. These results fit the hypothesis proposed by White, Speisman, and Costos (1983), according to which the first stage of the parent-adolescent relationship stresses the autonomy of adolescents as they seek to establish separateness of self from parents, whereas active and mutual interaction becomes more important during later adolescence. Nurmi (1987b) also found, in another study, that a positive atmosphere in the family increased the level of adolescents' future planning at the age of 11, whereas it decreased it at the age of 18. In all, these results suggest that the role of different dimensions of family interaction in the development of orientation to the future changes as a function of the adolescent's age.

However, the relationship between parental behavior and children's orientation to the future is more complex. Adolescent's thinking about and planning for the future may influence parental behavior as well. Those who are interested in major developmental tasks and who show high levels of planning skills are likely to be controlled less and allowed more independence than their contemporaries. Interestingly, when Seginer (1983) summarized research showing that high parental expectations were associated with children's high educational aspirations and academic performance, she also found that parents' expectations are influenced by their children's academic behavior. Consequently, family interaction should be described as a developing system rather than by simple causal links.

The review so far shows that, even though the majority of adolescents are interested in the major developmental tasks of their own age, their future-oriented goals, plans, and related causal attributions and affects vary to a great extent according to their age, sex, socioeconomic status, and family context. Looking at the relative influence of these factors provides some support for the model emphasizing the role of cultural and social context in the development of adolescents' future orientation. If the influence of several factors were to be considered simultaneously, it would be possible to categorize subgroups with considerable differences in their future orientation. However, such developmental differences have not been described so far. A need for future research in this area is evident.

Cross-Cultural Differences in Adolescents' Orientation to the Future

Not surprisingly, a number of cross-cultural differences have been found concerning adolescents' future orientation, reflecting the fact that young people's anticipated life-span development and their life context vary to a great extent across different cultures. Since only the major results are reviewed here, a summary of the samples and methods used, and the results of cross-cultural studies on adolescents' future orientation are presented in Table 2.

Adolescents' interests. In all, the studies show unexpected similarity in adolescents' interests across cultures: they all seem to be most interested in two main domains of their future life, work, and education (Gillispie & Allport, 1955; Seginer,' 1988a; Solantaus, 1987; Sundberg et al., 1983). Since education and work play a crucial role in expected life-span development in all the cultures involved in the research, these results are not so surprising. All the adolescents participating in the studies reviewed were at school and this may partly explain the cross-cultural similarities. Cultural differences may have emerged if adolescents, in particular from developing countries, who do not attend school, had been included.

In contrast, a number of studies show that adolescents from Anglo-American cultures more frequently express interest in their personal happiness, future family, and leisure activities, whereas young people from traditional societies, such as India, are more oriented to their parents' family, the health and death of others, the marriage of others, and societal topics (Gillispie & Allport, 1955; Sundberg et al., 1983). A different pattern emerges, however, if Anglo-American cultures are compared with rapidly urbanizing countries, such as Mexico and Singapore. Tallman, Marotz-Baden, and Pindas (1983), for example, found that Mexican adolescents placed greater value on material advancement in the future and emphasized saving and retraining to a greater extent than marriage and children compared with American youths. On the other hand, American adolescents emphasized family-oriented activities more than Mexican adolescents. Poole and Cooney (1987) found similar types of differences between Singaporean adolescents and Australian youths, as did Seginer (1988a) between Jewish adolescents living in a modern society and Arab adolescents growing up under transition from a rural to a modern way of life. Thus, even though education and career are dominant topics in adolescents' future outlook in all cultures, they have an especially important role for youths living in rapidly urbanizing societies such as Mexico and Singapore and for Israeli Arabs. One possible reason for this is that formal education in these societies provides better opportunities for real social success than in postindustrial societies and more traditional types of culture. However, in order better to understand these differences, more

detailed analysis of the cultures must be included in cross-cultural comparisons.

Solantaus (1987) also found cross-cultural differences in adolescents' thinking about the future in comparisons of adolescents from three Western types of society. The results show that Austrian adolescents, compared with British and Finnish adolescents, more frequently express hopes and worries concerning school and education, nuclear family, and human relations. On the other hand, British youths' hopes and worries exceed others' thinking in work and employment, material aspects of life and future family, while Finnish adolescents worry less than others about school and studies and more about war and other global affairs. These results seem to reflect a number of specific features of the societies compared. For example, societal problems threatening adolescents' future life, such as the high rate of unemployment in Great Britain, seem to be reflected in adolescents' orientation to the future. On the other hand, Solantaus et al. (1985) proposed that the high frequency of the fear of war among Finnish adolescents is due to the general antinuclear attitude in Finland and to the mass media, which often broadcasts programs on the subject.

Overall, these cross-cultural differences in interests seemed to reflect the differences in the typical developmental tasks of each culture as well as current societal features, e.g., level of unemployment. However, since cross-cultural studies have not involved measures of planning for the future or causal attributions and affects, we do not know the extent to which these aspects of adolescents' thinking vary.

Cross-cultural differences in sex roles. A number of studies show that sex differences in adolescents' orientation to the future are more evident in the traditional Societies compared with more urbanized ones. For example, in a summary of their study, Sundberg et al, (1983) stated that Indian adolescents showed the largest sex differences compared with American or Australian adolescents. Similar results comparing American and Indian adolescents were found by Heckel and Rajagopal (1975). Furthermore, Bentley (1983) found that Swazi girls were less interested in their future occupation and also had less extended future orientation compared with Swazi boys and Scottish adolescents.

The influence of sex also seems to vary across Western cultures. Solantaus (1987) found, for example, that girls and boys in Finland did not differ in their hopes and worries concerning work and employment, as girls and boys in Austria and Great Britain did. A comparison of the results of investigations by Mrnks (1968) and Lamm et al. (1976) and by Nurmi (1987b, 1989b) reveals a similar pattern. The major reason for these cross-cultural differences may be the fact that the high rate of urbanization in Finland during the last two decades, one of the highest in

TABLE 2
SUMMARY OF CROSS-CULTURAL STUDIES ON ADOLESCENTS' ORIENTATION TO THE FUTURE

Study	Sample cultures	Age	Method	Dependent variable	Results
Barton (1985)	409 British, 765 Finnish	12–15	Fears & hopes questionnaire	Content	British adolescents had more hopes concerning future occupation and more fears concerning unemployment, whereas Finnish youths were more concerned about the issue of peace and war.
Bentley (1983)	98 Scottish, 106 Swazi	12–25	Questions concerning the future, questionnaire	Content, extension	Swazi girls were less interested in their future occupation and they showed less extended future orientation compared with other groups. Scottish adolescents were less interested in their future family but more in their personal happiness compared with Swazi adolescents.
Chivian et al. (1985)	913 Americans, 293 Soviets	12–13	Future concerns questionnaire	Content	For Americans the item of greatest concern was the death of parents, whereas for Soviet adolescents it was nuclear war and other global issues.
Gillispie & Allport (1955)	United States, New Zealand, South Africa, (White, Bantus, Indians) Egypt, Mexico, France, Italy, Germany, Israel	University students	Future autobiography	Content, optimism	Women were more family oriented than men, whereas men were more concerned with economic values. American students were more interested in their own future family and less in their parental family compared with youths from other countries. American adolescents oriented typically toward

					and internal in their future thinking compared with other groups of students.
					Egyptians, Mexicans, Africans, and Bantu students were relatively nationalistic and concerned about social matters.
					French, German, and Italian adolescents were **pessimistic and interested in building a consistent** personal character. The outstanding feature of the **Japanese compared with other students was the** stressing of virtues of duty and moral convention.
Kuo & Spees (1983)	197 American, 147 Chinese (Taiwan)	17–22	Academic goals questionnaire	Academic goals	Academic goals for Chinese students were related to acquiring personal knowledge, while for Americans to obtaining professional qualifications.
					Chinese students said more often than Americans that their parents were most influential in deciding their major field of study.
Meade (1968)	40 Americans, 40 Hindus	About 20	Goal setting in simple task	Level of goals	American students were more realistic in their goal setting.
Meade (1971)	50 Americans, 50 Hindus	Male college students	Sentence completion	Past vs. future orientation, externality	Americans were more future oriented and internal compared with Hindu students.
					The parental family takes more care of Hindu students'

TABLE 2—*Continued*

Study	Sample cultures	Age	Method	Dependent variable	Results
Meade (1972)	50 from communities of the U.S., Brahmia, Kshatriya, Vasiya, Sudra, Muslim, Sikh, and Parsee, in India	Male college students	Sentence completion	Past vs. future orientation, achievement motivation	American males tend to be more future oriented and to have stronger achievement motivation compared with Brahmins, Vasiyas, Sudras, and Muslims. However, no differences between Americans and Kshatriyas, Parsees, and Sikhs were found.
Mehta et al. (1972)	182 Americans, 184 Indians	13–15	Future events questionnaire	Content, extension (years)	Education and work were the most often mentioned contents of future events by both sexes in both countries.
	48 Americans, 149 Indians				The Americans were more interested in their own marriage, children, and leisure activities, whereas Indians were more likely to refer to their own health and other people's courtship, marriage, and children as well as the death of others.
					Indian girls mentioned work more frequently than American girls, whereas American girls referred more often to autonomy.
					In both countries, the high status adolescents show

Poole & Cooney (1987)	440 Australians, 162 Singaporeans	14–15	Future events questionnaire	Content, extension (years), affects	Singaporean adolescents were more interested in future education and work but less in topics concerning their future marriage.
					Australian adolescents had shorter median extension than Singaporean youths.
					Singaporean adolescents had a more positive outlook about the future of society compared with Australians.
					Australian females were more interested in their future family compared with Australian males, whereas the converse was true for the Singaporean adolescents.
Poole, Sundberg, & Tyler (1982)	About 200 Americans, Indians, and Australians	13–15	Decision-making questionnaire	Auton. of decision-making	American adolescents indicated the greatest degree of autonomy followed by Australians.
					The family members have more power in decision-making about adolescents' future in India compared with the U.S. or Australia.
Seginer (1988a)	112 Israeli Jews, 116 Israeli Arabs	High-school seniors	Hopes & fears questionnaire	Content, specificity	Jewish adolescents expressed fewer concerns than Arab adolescents in future education, work, career, and collective issues.
					Arab adolescents had a more detailed and concrete concept of future marriage and family.
					Arab females had more higher education concerns than

TABLE 2—*Continued*

Study	Sample cultures	Age	Method	Dependent variable	Results
Solantaus (1987)	600 Austrians, 596 British, 665 Finnish	11–15	Hopes & fears questionnaire	Content	The most frequent hope in each country concerned work and employment. The top worry among Austrians was school and studies, among the British work, and employment, and among Finnish adolescents nuclear war.
					Austrian adolescents expressed more often than others hopes and worries about school and studies, nuclear family and other human relations.
					British respondents' hopes and worries exceeded others in work and employment, the material aspects of life, and their future family.
					Finnish adolescents worried more about war, global affairs, and their own health compared with other groups.
					Finnish adolescents had sex differences in fewer categories than others.
					Adolescents from all countries expressed more hopes and worries about work and employment with age. Only among Finns did hopes concerning their future family increase with age.
Sundberg, Poole &	100–300 Americans, Indians &	14–15	Future events questionnaire	Content, extension	All the groups agreed about their two top future events, education and work.

					acquisitions. Indian adolescents mentioned more frequently than other groups courtship and the marriage of others, health, the death of others, and specific occupations.
					The Indian sample showed the largest sex differences, with girls showing a short time span and boys looking farthest into the future.
Sundberg et al. (1969)	240 Americans, 182 Indians	14–15	Decision-making questionnaire	Autonomy of decision-making	Indian adolescents perceived their families as being more cohesive than Americans, while American adolescents perceived themselves as more autonomous and decisive.
					In India, the father was influential in decisions concerning the boys' future, while in the U.S., the mother ranked higher in perceived influence.
Sundberg & Tyler (1970)	48 Americans, 48 Indians, 48 Dutch	14–15	Occupation and free-time activities check-list	Content	Dutch adolescents have the widest variety of occupational possibilities, American boys and Indian girls the smallest.
					Americans listed most free-time activities and Indian adolescents least.
Tallman, Marotz-Baden, & Pindas (1983)	American & Mexican adolescents and their parents	12–15	Future decision-making game, interview	Content, family decision-making structure	Mexican adolescents place greater value on material advancement in the future, whereas Americans stressed family-oriented activities more.
					Mexican parents were more optimistic about their children's future than Americans.
					Mexican families were more patriarcal in the planning of adolescents' future, whereas power related to

Western Europe, has radically influenced the position of Finnish women (Position of Women, 1984). Consequently, the fact that working outside the home is an essential part of anticipated life-span development for Finnish women is also reflected in girls' thinking about the future.

In all, the results indicate that sex differences in adolescents' interests have their basis in the cultural context in which adolescents are living and in the related knowledge of anticipated life-span development.

Family decision making. A number of studies show that parents' role in their children's decision making concerning the future varies to great extent across different cultures. For example, Poole, Sundberg, and Tyler (1982) found that American adolescents indicated the greatest degree of autonomy followed by Australians, whereas Indian adolescents showed least autonomy. On the contrary, Sundberg, Sharma, Rohila, and Wodtli's (1969) results showed that Indian adolescents also perceived their families as being more cohesive compared with American youths. Tall-man et al. (1983) found that Mexican families, compared with American, were more patriarchal in planning their adolescents' future, whereas the power related to the planning was more equally distributed across family members in the United States. These results are of more general interest because they suggest that the unit of planning for the future also changes across cultures: while in Western societies, planning for the future is mainly carried out by adolescents themselves, the whole family participates in more traditional types of society. Thus, in these societies, research into individual future planning may be an inadequate way of studying the whole issue of orientation to the future.

RESEARCH ON PERTINENT TOPICS

The review has so far concentrated on the development of future-oriented motivation, planning, and evaluation. However, research has also been carried out on pertinent aspects of adolescent development, such as identity formation and career decision making. A summary of some of the findings follow, in as far as they add to out knowledge about adolescents' future orientation.

Identity Formation

Research on identity development, in particular that based on the identity status approach (Marcia, 1980) and the more recent process approach (Bosma, 1985), is Closely related to the development of orientation to the future. In Marcia's (1980) model the identity status of adolescents, i.e., whether they are in the identity achievement, foreclosure, identity diffusion, or moratorium stage, is determined by three factors: (1) the content of commitment (e.g., vocational, ideological, and sexual orientation), (2) the amount of exploration in these areas, and, finally, (3) the strength of commitment to specific decisions (Bosma, 1985). In fact, each of these

factors can be described in terms of future orientation. Content of commitment is closely related to that of future-oriented motivation. On the other hand, exploration is a perquisite of effective planning, because it provides knowledge about different alternatives for future life. Strength of commitment refers to the extent to which adolescents are motivated to realize their specific goals. Rappaport et al. (1985) found recently that the achievement and foreclosure groups, being characterized by high levels of commitment, generally scored more highly on measures of futurity than the diffusion and moratorium groups, showing a low level of commitment.

Bosma (1985) reformulated Marcia’s structural approach and described identity formation as a developmental process. According to him, the content of commitment depends on personal needs and the opportunities offered by society. Therefore, commitment is not restricted to occupation, ideology, and sex, but can occur in any personally relevant areas. Bosma also suggests that, even though the strength of commitment varies developmentally, it is not always stronger in older adolescents than in younger ones.

Bosma's (1985) results concerning identity formation are also similar to those reviewed here. He found, for example, that school, occupation, leisure-time activities, friendship, and parents were among the most important topics of exploration and commitment related to identity formation. Moreover, he showed that lack of interest in politics and ideological issues is striking among adolescents, even though these domains of life are expected to be one of the major topics of identity formation (Marcia, 1980). Sex differences found by Bosma (1985) were also similar to those reviewed here: females more often considered interpersonal areas to be important, whereas males highlighted school, occupation, politics, and money. Bosma also found that older subjects had stronger commitment than younger ones, but that the strength of commitment varied in different contents. However, no clear age differences were found with regard to the amount of exploration. This may be due to the fact that the youngest age group of Bosma's study consisted of 13- to 16-year-old adolescents who might be expected already to have begun their identity formation.

It has also been found that the influence of family relationships on adolescent identity formation is similar to their influence on orientation to the future. Since a number of reviews have been published on this topic (Grotevant & Cooper, 1986; Marcia, 1980; Waterman, 1982), only a brief summary of the findings follow. First, foreclosures (being low in exploration but high in commitment) seem to have closest relationships with their parents compared with other groups. There is considerable pressure and support for adolescent conformity to family values among foreclosure families (Marcia, 1980). Second, the parents of identity diffusion adolescents (lacking both exploration and commitment) have been characterized as indifferent, inactive, nonunderstanding, and negative (Waterman, 1982). These parents do not encourage adolescent participation, which is also reflected in the fact that adolescents are passive in family interaction (Grotevant & Cooper, 1986). Moratorium adolescents (showing high exploration but low commitment) seem to have an ambivalent relationship with their parents, whereas identity achievers (high exploration and high commitment) show positive but moderately ambivalent family relationships (Waterman, 1982). Both moratorium and identity achievement adolescents have been shown to be critical of their parents and also likely to report themselves as being in conflict with their family (Waterman, 1982).

In sum, close parent-child relationships seem to increase the likelihood of early commitment in decisions concerning major developmental tasks. Research on adolescents' future orientation showed similar results (e.g., Nurmi, 1987b). Powers, Hauser, Schwartz, Noam, and Jacobson (1983) also found that adolescent ego development was most advanced when families presented a high level of noncompetitive sharing of perspectives or challenging behavior within the context of firm support. On the other hand, a critical attitude toward parents seems to increase the amount of exploration, perhaps because the parental model is found to be unsatisfactory. However, Cooper, Grotevant, and Condon (1983) and Bell and Bell (1983) reported results showing that disagreement with the mother and the father influence the adolescent child's exploration, ego development and positive self-regard in different ways.

In all, research on identity formation provides a somewhat similar view to adolescent development as does research on future orientation.

Career Decision Making

It was shown earlier that two of the major topics of adolescents' future-oriented interests were occupation and education. It is not therefore surprising that vocational development has been conceptualized somewhat similarly to future-orientation (Harren, 1979; Heppner, 1978). For example, Harren (1979) described career decision making in terms of a four-stage sequential process: awareness, planning, commitment, and implementation. First, based on the awareness of his or her present level of success and satisfaction, the individual recognizes the need to explore alternatives and begin planning. Second, the planning stage consists of exploring task- and self-related information and settling upon a specific alternative. Third, the individual incorporates and integrates commitment with his or her self-concept system and, simultaneously, exaggerates the positive aspect of the chosen alternative. Finally, during the implementation stage, the individual is inducted into the new context, then reacts to it and, finally, is assimilated into it.

Taylor (1985) investigated the role of occupational and self-related knowledge in career development. She found, for example, that occupational knowledge and vocational self-concept crystallization influenced students' school-to-work transition: both the levels of occupational knowledge and the awareness of vocational abilities and interests predicted the extent to which students received job offers both before and after college graduation. Similarly, Neimeyer, Nevill, Probert, and Fukuyama (1985) found that highly integrated occupational schemata were associated with more effective vocational decision making. Taylor's (1985) results further indicated that occupational knowledge was related to increased exposure to job information provided by others. Self-concept crystallization, on the other hand, was related to different experimental activities relevant to the future occupation.

Since research on career decision making has recently been reviewed elsewhere (Osipow, 1983; Tinsley & Heesacker, 1984; Zunker, 1986), it is not discussed in detail here. However, findings do seem to give a view of adolescent development somewhat similar to the present review of adolescents' orientation to the future. For example, older adolescents have been shown to indicate more concern for vocational opportunities and information about careers than younger ones (Osipow, 1983). Females have been shown to score more highly than males on homemaking commitment and career commitment, and males have been shown to express stronger sentiment for combining home and career. On the other hand, boys and girls were not found to differ significantly in their actual knowledge about occupations (Tinsley & Heesacker, 1984). Moreover, relatively more intelligent adolescents have been shown to plan more effectively in general than their less intelligent contemporaries (Osipow, 1983).

The recent models and results concerning vocational development were found to be similar to those concerning adolescents' orientation to the future. However, although career decision making plays an important part in orientation to the future, it is only one aspect of a complex process in which people individually cope with different developmental tasks.

ADOLESCENT PROBLEM BEHAVIOR AND ORIENTATION TO THE FUTURE

Although the majority of adolescents were shown to be motivated to plan their future, there is, however, a group of young people who are not interested in major developmental tasks. Nurmi (1989b), for example, found that 16% of 11- and 15-year-olds did not mention topics related to future occupation or education when they were interviewed about their future goals and plans. Even though it is a minority group, it is an important one, because its members may manifest other types of problem behavior as well, such as delinquency, problems in school and drug use. A summary of research on the relationship between adolescent problem behavior and future orientation follows.

Trommsdorff and Lamm (1980) reviewed research about delinquents' future orientation and concluded that the findings are contradictory. According to theory, the stereotype delinquent who ignores the possible future consequences of his or her present behavior, acts more impulsively and is less inclined in delay of gratification has been found to be difficult to establish. However, research does seem to suggest that the future orientation of delinquents is less optimistic (Rychlack, 1973; Trommsdorff & Lamm, 1980), less structured (Trommsdorff & Lamm, 1980), less extended (Black & Gregson, 1973; Siegman, 1961) and more oriented toward private concerns (Trommsdorff & Lamm, 1980) compared with normal adolescents. However, as the results are correlational by nature, it is impossible to know whether less extended, less structured, and less pessimistic future orientation increases the likelihood of delinquent behavior or vice versa. For example, general pessimism and present orientation may be followed by behavior which is not influenced by possible negative consequences. Another possibility is that being labelled as delinquent, and the related life context, provide a basis for pessimism and short temporal extension.

A few studies have looked at how institutionalization, a typical life situation for delinquents, influences adolescents' orientation to the future. Trommsdorff and Lamm (1980), for example, suggested that the temporarily institutionalized person's orientation to the future reflects the fact that a new beginning must be made following release: imprisoned delinquents noted more fears pertaining to family life and personal development and more hopes pertaining to occupation compared with a sample of normal individuals. One typical problem of institutionalized delinquents may be that the time for solving different age-specific developmental tasks, such as future education, occupation, and marriage, has passed by the time of their release. This may cause extra problems for them as they try to begin a normal adult life.

Landau (1969) also found that the date of release was a significant boundary for the inmate's future orientation: the nearer it was, the less extended was the future orientation. This corresponds with the findings reviewed here suggesting that anticipated life-span events provide a basis for future-oriented interests and plans. Furthermore, Landau (1976) showed that the closer the prisoner is to his release, the greater the similarity between him and noninstitutionalized people.

Little research has been carded out on the relationship between future orientation and other types of problem behavior. Trommsdorff (1986) found that drug-using delinquents were more pessimistic than nonuser delinquents. Gilchrist and Schinke (1987) recently reviewed studies showing that adolescents who postpone sexual activity tend to have better developed problem-solving and decision-making skills and future orientation. Moreover, young people who experience heterosexual and contraceptive problems appear to have a limited sense of options, poor self-understanding, and strong denial that pregnancy is a possible consequence of their behavior. However, as these results are based on correlational procedures, it is also possible that the life context of adolescents showing problem behavior influences their orientation to the future. For example, although Mindick, Oskamp, and Berger (1977) showed that people who suffer contraceptive failures exhibit shorter temporal extension than a control group, they further suggest that differences in future orientation are more likely to be due to changes in life context after the experience of being pregnant than to a general attitude toward the future.

In all, these results seem to suggest that adolescents showing a variety of problem behavior see their future differently from their contemporaries. However, some of these differences seemed to be consequences rather than causes of problem behavior. An interesting approach to this issue of causality was put forward recently by Trommsdorff (1986). She suggested that delinquents' thinking about the future may be part of developmental cycles that are reinforced as different types of global strategy. Pessimistic future orientation, for example, influences adolescents' environmental conditions in a way that also reinforces original negative anticipations. In this case, pessimistic, less extended, and less structured future orientation assumes self-fulfilling qualities.

SUMMARY AND CONCLUSIONS

Adolescents' Orientation to the Future

The review showed that the content and temporal extension of adolescents' interests and goals variously reflect expected life-span development, characterized in life-span approach as developmental tasks (Havighurst, 1948/1974), normative life-tasks (Dittmann-Kohli, 1986) or "milestone events" (Lessing, 1972), and their "normative time-table" (Bengtson & Black, 1973). Moreover', as adolescents grow older, they first become interested in the developmental tasks of late adolescence (education) and then in tasks of early adulthood (future occupation and family) (Nurmi, 1989a). However, irrespective of their age, young people were interested in the life events they expected to be actualized at the end of the second and the beginning of the third decade of life. It therefore follows that younger adolescents' thinking extends further into the future measured by years compared with relatively older ones. Interestingly enough, it has recently been shown that only few adolescents extend their thinking to events expected to be realized after the age of 30 (Nurmi, 1989b). Consequently, an important task for future research would be to study how orientation to the future develops during early adulthood, after the expected realization time of the goals set during adolescence has passed by. Nurmi (1989e) recently reported preliminary data showing that, while interests in future education and family decrease during early adulthood, those relating to work and property do not. Moreover, in middle age, people seem to become increasingly interested in their children's future and their own health preoccupies them in old age.

Adolescents' fears and worries relating to the future, on the other hand, concerned threats related to the fulfillment of the major normative life-tasks (unemployment, divorce), non-normative life-events related to their parents' family (death and divorce of parents), and global historical events (nuclear war).

The review also revealed that, although children in their early teens already have basic planning skills (Oppenheimer, 1987), the levels of planning, realization, and knowledge concerning the future increase with age up to the early 20s. Since differences in cognitive skills measured by intelligence tests seem to explain only a small proportion of individual variance in planning activity, it was suggested that changes in life-span-related opportunities for meaningful planning are also responsible for the increase in planning for the future during adolescence. Similarly, Cantor and Kihlstrom (1987) discussed the importance of the careful analysis of the life context to which individuals apply their intelligence. Future research, therefore, could well investigate the development of planning for the future taking into account changes in planning skills, the level of knowledge of specific life domains, and changes in contextual factors. The studies which were reviewed covering the third process, evaluation, revealed that adolescents' thinking about the future becomes more internal with age. Boys in particular become more optimistic, whereas girls showed a tendency to become more pessimistic. Experiencing more challenges, responding less positively to challenge, and simultaneous negative self-appraisal seem to render girls more susceptible to anxiety, and thus to depressive affect, in adolescence (review: Petersen, 1988). One source for the increased amount of challenge for girls may be the conflict in the modern female role between achievement pressures in the areas of both future family and occupation. However, since only a few studies have investigated the development of causal attributions and affects concerning the future, there is an evident need for future research on this topic.

The review also showed that a number of factors in the life context, such as family relationships, sex roles, and socioeconomic status, influenced adolescents' orientation to the future. The level of parental control and the goals they have concerning their children's future were found to influence adolescents' future-oriented interests. Moreover, parents seem to provide a model for how adolescents plan to solve different developmental tasks, in particular that of intimacy. Parental support was found to increase adolescents' optimism and internality concerning the future. On the other hand, the effects of sex roles and socioeconomic status were interpreted as being due to the differences in anticipated life span development between the subgroups compared. For example, it was suggested that adolescents with high socioeconomic status extend further into the future than those with a low socioeconomic background because of differences between the groups in the expected time of realization of the principal developmental tasks (Boocock, 1978). Similarly, it appears that the sex differences in adolescents' interests, and how far into the future they extend, are due to the differences in boys' and girls' anticipated life-span development.

Finally, although adolescents from a number of cultures seem to agree about two main domains of their interests, future work and education, consistent cross-cultural differences were also found: adolescents from Anglo-American cultures are relatively more interested in leisure activities and personal happiness, adolescents from countries with a high rate of urbanization seem to be relatively more interested in future education and career, whereas adolescents from traditional cultures are most concerned about topics related to their parents' family. It was also interesting to note that, in traditional societies such as India and Mexico, parents and family participate in the planning of adolescents' future to a greater extent than in Anglo-American cultures.

Theoretical Framework

In this review, orientation to the future was described in terms of three processes, motivation, planning activity, and evaluation. People first set goals based on comparison between their motives and values and their expectations concerning the future. Second, they must work out how to realize these goals, which is typically done by means of planning. Third, people evaluate the possibility of achieving their goals and actualizing the plans they have constructed. Causal attributions and affects concerning the future were thought to play an important part in this evaluation. Orientation to the future was also described from a contextual point of view. It was suggested that normative life events and their timetable provide the context in which people's future-oriented goals and interests develop arid that life-span-related changes in action opportunities were the basis of the development of future-oriented plans and strategies. Moreover, it seems that standards and deadlines for the successful solution of life-tasks may spark off the evaluation process involved in orientation to the future. These contextual influences are seen as being mediated by cultural knowledge about anticipated life-span development. The basic processes in the development of orientation to the future in family context were also described. It was suggested that, by setting normative standards, tutoring, and providing role models and support, parents influence their children's future orientation.

This framework differs in a variety of ways from existing ones in this research field (reviews: Hoornaert, 1973; Rakowski, 1979, de Volder, 1979). Earlier research typically described future-orientation in terms of intraindividual properties. Efforts were made to establish its antecedents (e.g., Klineberg, 1967) and consequences (Agarwal, Tripathi, & Srivastava, 1983; Gjesme, 1981). The main focus of this trait-theoretical approach was the investigation of individual differences in interest in the future and in how far into the future thinking extends, and so on. Moreover, orientation to the future was described in terms of this specific research field which was not associated with general psychological theory (Hoornaert, 1973; de Voider, 1979). By way of contrast, future orientation is now placed in the context of modern psychological concepts, such as goals, plans, schemata, attributions, and affects. It is described as a process consisting of different substages rather than individual traits. Furthermore, emphasis is placed on the role of contextual factors, such as age-related life-tasks, action opportunities, and developmental standards, in the development of future orientation. The application of this theoretical approach provided the opportunity to reinterpret the research field and to find a straightforward pattern of results not afforded by earlier reviews (Rakowski, 1979; de Voider, 1979). The framework also facilitated comparison of research on future orientation with other pertinent areas, such as the development of planning skills, identity formation, and career decision making. For example, describing orientation to the future in terms of goal-setting, planning, and evaluation in different domains of life helped to identify connections between future orientation and identity formation as well as some similarities in the two research fields. Finally, an attempt was made to describe the development of orientation to the future in a family context. Although the developmental processes involved in the model are relatively general, the framework was useful in interpreting results concerning the development of adolescents' future orientation and in suggesting directions for future research. The nature of development has been discussed earlier (Trommsdorff, 1983, 1986), but no similar systematic description has been presented.

Although this approach is a general framework rather than a model that can be tested in one or two studies, two types of evidence for its construct validity already exist. Nurmi (1989c) recently used confirmatory factor analysis to illustrate that the model consisting of three latent constructs, motivation, planning, and evaluation, fitted the covariance matrix of seven observed variables based on interview data about adolescents'

goals and hopes. The present review also provided some evidence of construct validity (Nunnally, 1978): the variables that were related to the same theoretical construct showed a similar pattern of results, in particular in relation to one major variable, age.

The conceptualization presented here also proved useful in reviewing studies on adolescents' future orientation and planning. Since the framework facilitates the organization of earlier research, contrary to some previous reviews (Rakowski, 1979; de Volder, 1979), a number of consistent findings emerged. For example, by emphasizing the importance of the content of goals and expectations as indicators of future-oriented motivation, it was possible to bring out consistent similarities in adolescents' orientation to the future across different studies applying slightly different methods. Moreover, evident developmental changes in adolescents' future-oriented interests were found. Emphasizing the role of anticipated life-span development in the formation of future-oriented goals made it easier to understand why extension, when measured as years from the time of the study, decreased with age. It also made it possible to put forward preliminary explanations for differences in adolescents' future orientation in relation to sex, socioeconomic status, and culture. For example, the review showed that differences in temporal extension between adolescents with high and low socioeconomic status are due to the differences in their anticipated life-span development. Based on the contextual approach, it was also suggested that any increase in planning for the future with age may reflect changes in the planning context rather than the development of planning skills. Conceptualizing evaluation in terms of causal attributions and affects also provides the basis for understanding that both internality and optimism seem to show similar developmental patterns. The model also predicted the importance of self-esteem to causal attributions, which was found in a few studies (Nurmi, 1989d; Plante, 1977). The traditional approach characterizing future orientation as a personality trait does not serve to explain these findings (de Voider, 1979).

Although the framework presented is a general approach rather than a specific model, it is possible to set out a number of hypotheses, the validity of which can be tested. First, the results showed that adolescents' future-oriented goals and their temporal extension reflected expected life-span development. This could be further tested by comparing two groups of adolescents living in cultural settings which differ radically in relation to anticipated life-span development. If it was found that future-oriented goals and related temporal extension were similar despite the evident differences in anticipated life-span development, it would mean the model was flawed.

Second, any relevant change in knowledge concerning the anticipated life-span development might be expected to be followed by changes in specific goals. For example, providing adolescents with forecasts about the future development of labor markets should influence their vocational goals. On the other hand, any increase in people's self-esteem, due to therapeutic interventions, for example, should be followed by more internal beliefs in their own influence over their future.

Third, although adolescents' interests and goals were shown to reflect expected life-span development, earlier research did not provide data about the extent to which contextual factors influence the development of planning and evaluation. However, on the basis of the theoretical framework, it might be expected that age-related changes in action opportunities, for instance those concerning educational choices, influence future planning irrespective of changes in individual planning skills. This type of increase in the level of planning, which is due to contextual changes, should occur relatively rapidly in any specific domain of life, and there should be no similar increase in relation to other domains. Moreover, if normative standards for solving age-specific developmental tasks apply, adolescents who have not succeeded in realizing a specific developmental task at certain ages might be expected to display increasing anxiety and decreasing self-esteem. This is a somewhat similar phenomenon to the moratorium state in identity formation literature (Marcia, 1980).

Next, evident changes in the content of future-oriented goals are likely during early adulthood as age-specific developmental tasks change. Nurmi (1989e) recently presented preliminary data showing that changes in adults' interests with age also reflect age-related life-tasks.

Finally, the developmental aspects of the framework can be tested by investigating the extent to which adolescents' goal-setting is based on goals, values, and standards that are typical of their parents, the extent to which parents' knowledge of different domains of life is associated with adolescents' skills and coping resources, and the extent to which parental support is related to adolescents' evaluation of their future. By contrast, other relationships between future orientation and the different dimensions of family interaction would discredit the model. One example would be if parental support were shown to correlate positively with either the level of adolescents' goals or the complexity of their plans without any association with causal attributions and affects.

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