Science on Adolescent Development

"The body of scientific study…continues to confirm that compared with adults, the unique developmental characteristics of adolescents' brains lead to more impulsive behavior, the failure to comprehend consequences, and an underdeveloped sense of self, all of which may cause poor decisions and reckless actions. Adolescents also are particularly susceptible to negative environmental influences, which in turn may influence brain biology in a way that compounds the characteristics associated with their unique developmental stage…The very immaturity and plasticity that create an increased propensity for wrongdoing in adolescents also provide an enormous capacity for learning, development, and growth."

- Brief of Mental Health Experts
In Support of Petitioners *Jackson* and *Miller*

Science on Adolescent Development

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What's Wrong With the Teenage Mind?

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By ALISON GOPNIK

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Children today reach puberty earlier and adulthood later. The result: A lot of teenage weirdness. Alison Gopnik on how we might readjust adolescence.

What was he thinking?" It's the familiar cry of bewildered parents trying to understand why their teenagers act the way they do.

Photo Source: Harry Campbell

How does the boy who can thoughtfully explain the reasons never to drink and drive end up in a drunken crash? Why does the girl who knows all about birth control find herself pregnant by a boy she doesn't even like? What happened to the gifted, imaginative child who excelled through high school but then dropped out of college, drifted from job to job and now lives in his parents' basement?

If you think of the teenage brain as a car, today's adolescents acquire an accelerator a long time before they can steer and brake.

Adolescence has always been troubled, but for reasons that are somewhat mysterious, puberty is now kicking in at an earlier and earlier age. A leading theory points to changes in energy balance as children eat more and move less.

At the same time, first with the industrial revolution and then even more dramatically with the information revolution, children have come to take on adult roles later and later. Five hundred years ago, Shakespeare knew that the emotionally intense combination of teenage sexuality and peer-induced risk could be tragic—witness "Romeo and Juliet." But, on the other hand, if not for fate, 13-year-old Juliet would have become a wife and mother within a year or two.

Our Juliets (as parents longing for grandchildren will recognize with a sigh) may experience the tumult of love for 20 years before they settle down into motherhood. And our Romeos may be poetic lunatics under the influence of Queen Mab until they are well into graduate school.

What happens when children reach puberty earlier and adulthood later? The answer is: a good deal of teenage weirdness. Fortunately, developmental psychologists and neuroscientists are starting to explain the foundations of that weirdness. The crucial new idea is that there are two different neural and psychological systems that interact to turn children into adults. Over the past two centuries, and even more over the past generation, the developmental timing of these two systems has changed. That, in turn, has profoundly changed adolescence and produced new kinds of adolescent woe. The big question for anyone who deals with young people today is how we can go about bringing these cogs of the teenage mind into sync once again.

The first of these systems has to do with emotion and motivation. It is very closely linked to the biological and chemical changes of puberty and involves the areas of the brain that respond to rewards. This is the system that turns placid 10-year-olds into restless, exuberant, emotionally intense teenagers, desperate to attain every goal, fulfill every desire and experience every sensation. Later, it turns them back into relatively placid adults.

Recent studies in the neuroscientist B.J. Casey's lab at Cornell University suggest that adolescents aren't reckless because they underestimate risks, but because they overestimate rewards—or, rather, find rewards more rewarding than adults do. The reward centers of the adolescent brain are much more active than those of either children or adults. Think about the incomparable intensity of first love, the never-to-be-recaptured glory of the high-school basketball championship.

What teenagers want most of all are social rewards, especially the respect of their peers. In a recent study by the developmental psychologist Laurence Steinberg at Temple University, teenagers did a simulated high-risk driving task while they were lying in an fMRI brain-imaging machine. The reward system of their brains lighted up much more when they thought another teenager was watching what they did—and they took more risks.

From an evolutionary point of view, this all makes perfect sense. One of the most distinctive evolutionary features of human beings is our unusually long, protected childhood. Human children depend on adults for much longer than those of any other primate. That long protected period also allows us to learn much more than any other animal. But eventually, we have to leave the safe bubble of family life, take what we learned as children and apply it to the real adult world.

Becoming an adult means leaving the world of your parents and starting to make your way toward the future that you will share with your peers. Puberty not only turns on the motivational and emotional system with new force, it also turns it away from the family and toward the world of equals.

The second crucial system in our brains has to do with control; it channels and harnesses all that seething energy. In particular, the prefrontal cortex reaches out to guide other parts of the brain, including the parts that govern motivation and emotion. This is the system that inhibits impulses and guides decision-making, that encourages long-term planning and delays gratification.

This control system depends much more on learning. It becomes increasingly effective throughout childhood and continues to develop during adolescence and adulthood, as we gain more experience. You come to make better decisions by making not-so-good decisions and then correcting them. You get to be a good planner by making plans, implementing them and seeing the results again and again. Expertise comes with experience. As the old joke has it, the answer to the tourist's question "How do you get to Carnegie Hall?" is "Practice, practice, practice."

In the distant (and even the not-so-distant) historical past, these systems of motivation and control were largely in sync. In gatherer-hunter and farming societies, childhood education involves formal and informal apprenticeship. Children have lots of chances to practice the skills that they need to accomplish their goals as adults, and so to become expert planners and actors. The cultural psychologist Barbara Rogoff studied this kind of informal education in a Guatemalan Indian society, where she found that apprenticeship allowed even young children to become adept at difficult and dangerous tasks like using a machete.

In the past, to become a good gatherer or hunter, cook or caregiver, you would actually practice gathering, hunting, cooking and taking care of children all through middle childhood and early adolescence—tuning up just the prefrontal wiring you'd need as an adult. But you'd do all that under

expert adult supervision and in the protected world of childhood, where the impact of your inevitable failures would be blunted. When the motivational juice of puberty arrived, you'd be ready to go after the real rewards, in the world outside, with new intensity and exuberance, but you'd also have the skill and control to do it effectively and reasonably safely.

In contemporary life, the relationship between these two systems has changed dramatically. Puberty arrives earlier, and the motivational system kicks in earlier too. At the same time, contemporary children have very little experience with the kinds of tasks that they'll have to perform as grown-ups. Children have increasingly little chance to practice even basic skills like cooking and caregiving. Contemporary adolescents and pre-adolescents often don't do much of anything except go to school. Even the paper route and the baby-sitting job have largely disappeared.

The experience of trying to achieve a real goal in real time in the real world is increasingly delayed, and the growth of the control system depends on just those experiences. The pediatrician and developmental psychologist Ronald Dahl at the University of California, Berkeley, has a good metaphor for the result: Today's adolescents develop an accelerator a long time before they can steer and brake.

This doesn't mean that adolescents are stupider than they used to be. In many ways, they are much smarter. An ever longer protected period of immaturity and dependence—a childhood that extends through college—means that young humans can learn more than ever before. There is strong evidence that IQ has increased dramatically as more children spend more time in school, and there is even some evidence that higher IQ is correlated with delayed frontal lobe development.

All that school means that children know more about more different subjects than they ever did in the days of apprenticeships. Becoming a really expert cook doesn't tell you about the nature of heat or the chemical composition of salt—the sorts of things you learn in school.

But there are different ways of being smart. Knowing physics and chemistry is no help with a soufflé. Wide-ranging, flexible and broad learning, the kind we encourage in high-school and college, may actually be in tension with the ability to develop finely-honed, controlled, focused expertise in a particular skill, the kind of learning that once routinely took place in human societies. For most of our history, children have started their internships when they were seven, not 27.

The old have always complained about the young, of course. But this new explanation based on developmental timing elegantly accounts for the paradoxes of our particular crop of adolescents. There do seem to be many young adults who are enormously smart and knowledgeable but directionless, who are enthusiastic and exuberant but unable to commit to a particular kind of work or a particular love until well into their 20s or 30s. And there is the graver case of children who are faced with the uncompromising reality of the drive for sex, power and respect, without the expertise and impulse control it takes to ward off unwanted pregnancy or violence.

This new explanation also illustrates two really important and often overlooked facts about the mind and brain. First, experience shapes the brain. People often think that if some ability is located in a particular part of the brain, that must mean that it's "hard-wired" and inflexible. But, in fact, the brain is so powerful precisely because it is so sensitive to experience. It's as true to say that our experience of controlling our impulses make the prefrontal cortex develop as it is to say that prefrontal development makes us better at controlling our impulses. Our social and cultural life shapes our biology.

Second, development plays a crucial role in explaining human nature. The old "evolutionary psychology" picture was that genes were directly responsible for some particular pattern of adult

behavior—a "module." In fact, there is more and more evidence that genes are just the first step in complex developmental sequences, cascades of interactions between organism and environment, and that those developmental processes shape the adult brain. Even small changes in developmental timing can lead to big changes in who we become.

Fortunately, these characteristics of the brain mean that dealing with modern adolescence is not as hopeless as it might sound. Though we aren't likely to return to an agricultural life or to stop feeding our children well and sending them to school, the very flexibility of the developing brain points to solutions.

Brain research is often taken to mean that adolescents are really just defective adults—grown-ups with a missing part. Public policy debates about teenagers thus often turn on the question of when, exactly, certain areas of the brain develop, and so at what age children should be allowed to drive or marry or vote—or be held fully responsible for crimes. But the new view of the adolescent brain isn't that the prefrontal lobes just fail to show up; it's that they aren't properly instructed and exercised.

Simply increasing the driving age by a year or two doesn't have much influence on the accident rate, for example. What does make a difference is having a graduated system in which teenagers slowly acquire both more skill and more freedom—a driving apprenticeship.

Instead of simply giving adolescents more and more school experiences—those extra hours of after-school classes and homework—we could try to arrange more opportunities for apprenticeship. AmeriCorps, the federal community-service program for youth, is an excellent example, since it provides both challenging real-life experiences and a degree of protection and supervision.

"Take your child to work" could become a routine practice rather than a single-day annual event, and college students could spend more time watching and helping scientists and scholars at work rather than just listening to their lectures. Summer enrichment activities like camp and travel, now so common for children whose parents have means, might be usefully alternated with summer jobs, with real responsibilities.

The good news, in short, is that we don't have to just accept the developmental patterns of adolescent brains. We can actually shape and change them.

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BEAUTIFUL BRAINS

Moody. Impulsive. Maddening. Why do teenagers act the way they do? Viewed through the eyes of evolution, their most exasperating traits may be the key to success as adults.

PUBLISHED: October 2011

By David Dobbs

Although you know your teenager takes some chances, it can be a shock to hear about them.

Source: http://ngm.nationalgeographic.com/2011/10/teenage-brains/dobbs-text

One fine May morning not long ago my oldest son, 17 at the time, phoned to tell me that he had just spent a couple hours at the state police barracks. Apparently he had been driving "a little fast." What, I asked, was "a little fast"? Turns out this product of my genes and loving care, the boy-man I had swaddled, coddled, cooed at, and then pushed and pulled to the brink of manhood, had been flying down the highway at 113 miles an hour.

"That's more than a little fast," I said.

He agreed. In fact, he sounded somber and contrite. He did not object when I told him he'd have to pay the fines and probably for a lawyer. He did not argue when I pointed out that if anything happens at that speed—a dog in the road, a blown tire, a sneeze—he dies. He was in fact almost irritatingly reasonable. He even proffered that the cop did the right thing in stopping him, for, as he put it, "We can't all go around doing 113."

He did, however, object to one thing. He didn't like it that one of the several citations he received was for reckless driving. "Well," I huffed, sensing an opportunity to finally yell at him, "what would you call it?"

"It's just not accurate," he said calmly. "'Reckless' sounds like you're not paying attention. But I was. I made a deliberate point of doing this on an empty stretch of dry interstate, in broad daylight, with good sight lines and no traffic. I mean, I wasn't just gunning the thing. I was driving.

"I guess that's what I want you to know. If it makes you feel any better, I was really focused." Actually, it did make me feel better. That bothered me, for I didn't understand why. Now I do.

My son's high-speed adventure raised the question long asked by people who have pondered the class of humans we call teenagers: What on Earth was he doing? Parents often phrase this question more colorfully. Scientists put it more coolly. They ask, What can explain this behavior? But even that is just another way of wondering, What is wrong with these kids? Why do they act this way? The question passes judgment even as it inquires.

Through the ages, most answers have cited dark forces that uniquely affect the teen. Aristotle concluded more than 2,300 years ago that "the young are heated by Nature as drunken men by wine." A shepherd in William Shakespeare's *The Winter's Tale* wishes "there were no age between ten and three-and-twenty, or that youth would sleep out the rest; for there is nothing in the between but getting wenches with child, wronging the ancientry, stealing, fighting." His lament colors most modern scientific inquiries as well. G. Stanley Hall, who formalized adolescent studies with his 1904 *Adolescence: Its Psychology and Its Relations to Physiology, Anthropology, Sociology, Sex, Crime, Religion and Education,* believed this period of "storm and stress" replicated earlier, less civilized stages of human development. Freud saw adolescence as an expression of torturous psychosexual conflict; Erik Erikson, as the most tumultuous of life's several identity crises. Adolescence: always a problem.

Such thinking carried into the late 20th century, when researchers developed brain-imaging technology that enabled them to see the teen brain in enough detail to track both its physical development and its patterns of activity. These imaging tools offered a new way to ask the same question—What's wrong with these kids?—and revealed an answer that surprised almost everyone. Our brains, it turned out, take much longer to develop than we had thought. This revelation suggested both a simplistic, unflattering explanation for teens' maddening behavior—and a more complex, affirmative explanation as well.

The first full series of scans of the developing adolescent brain—a National Institutes of Health (NIH) project that studied over a hundred young people as they grew up during the 1990s—showed that our brains undergo a massive reorganization between our 12th and 25th years. The brain doesn't actually grow very much during this period. It has already reached 90 percent of its full size by the time a person is six, and a thickening skull accounts for most head growth afterward. But as we move through adolescence, the brain undergoes extensive remodeling, resembling a network and wiring upgrade.

For starters, the brain's axons—the long nerve fibers that neurons use to send signals to other neurons—become gradually more insulated with a fatty substance called myelin (the brain's white matter), eventually boosting the axons' transmission speed up to a hundred times. Meanwhile, dendrites, the branchlike extensions that neurons use to receive signals from nearby axons, grow twiggier, and the most heavily used synapses—the little chemical junctures across which axons and dendrites pass notes—grow richer and stronger. At the same time, synapses that see little use begin to wither. This synaptic pruning, as it is called, causes the brain's cortex—the outer layer of gray matter where we do much of our conscious and complicated thinking—to become thinner but more efficient. Taken together, these changes make the entire brain a much faster and more sophisticated organ.

This process of maturation, once thought to be largely finished by elementary school, continues throughout adolescence. Imaging work done since the 1990s shows that these physical changes move in a slow wave from the brain's rear to its front, from areas close to the brain stem that look after older and more behaviorally basic functions, such as vision, movement, and fundamental processing, to the evolutionarily newer and more complicated thinking areas up front. The corpus callosum, which connects the brain's left and right hemispheres and carries traffic essential to many advanced brain functions, steadily thickens. Stronger links also develop between the hippocampus, a sort of memory directory, and frontal areas that set goals and weigh different agendas; as a result, we get better at integrating memory and experience into our decisions. At the same time, the frontal areas develop greater speed and richer connections, allowing us to generate and weigh far more variables and agendas than before.

When this development proceeds normally, we get better at balancing impulse, desire, goals, self-interest, rules, ethics, and even altruism, generating behavior that is more complex and, sometimes at

least, more sensible. But at times, and especially at first, the brain does this work clumsily. It's hard to get all those new cogs to mesh.

Beatriz Luna, a University of Pittsburgh professor of psychiatry who uses neuroimaging to study the teen brain, used a simple test that illustrates this learning curve. Luna scanned the brains of children, teens, and twentysomethings while they performed an antisaccade task, a sort of eyes-only video game where you have to stop yourself from looking at a suddenly appearing light. You view a screen on which the red crosshairs at the center occasionally disappear just as a light flickers elsewhere on the screen. Your instructions are to not look at the light and instead to look in the opposite direction. A sensor detects any eye movement. It's a tough assignment, since flickering lights naturally draw our attention. To succeed, you must override both a normal impulse to attend to new information and curiosity about something forbidden. Brain geeks call this response inhibition.

Ten-year-olds stink at it, failing about 45 percent of the time. Teens do much better. In fact, by age 15 they can score as well as adults if they're motivated, resisting temptation about 70 to 80 percent of the time. What Luna found most interesting, however, was not those scores. It was the brain scans she took while people took the test. Compared with adults, teens tended to make less use of brain regions that monitor performance, spot errors, plan, and stay focused—areas the adults seemed to bring online automatically. This let the adults use a variety of brain resources and better resist temptation, while the teens used those areas less often and more readily gave in to the impulse to look at the flickering light—just as they're more likely to look away from the road to read a text message.

If offered an extra reward, however, teens showed they could push those executive regions to work harder, improving their scores. And by age 20, their brains respond to this task much as the adults' do. Luna suspects the improvement comes as richer networks and faster connections make the executive region more effective.

These studies help explain why teens behave with such vexing inconsistency: beguiling at breakfast, disgusting at dinner; masterful on Monday, sleepwalking on Saturday. Along with lacking experience generally, they're still learning to use their brain's new networks. Stress, fatigue, or challenges can cause a misfire. Abigail Baird, a Vassar psychologist who studies teens, calls this neural gawkiness—an equivalent to the physical awkwardness teens sometimes display while mastering their growing bodies.

The slow and uneven developmental arc revealed by these imaging studies offers an alluringly pithy explanation for why teens may do stupid things like drive at 113 miles an hour, aggrieve their ancientry, and get people (or get gotten) with child: They act that way because their brains aren't done! You can see it right there in the scans!

This view, as titles from the explosion of scientific papers and popular articles about the "teen brain" put it, presents adolescents as "works in progress" whose "immature brains" lead some to question whether they are in a state "akin to mental retardation."

The story you're reading right now, however, tells a different scientific tale about the teen brain. Over the past five years or so, even as the work-in-progress story spread into our culture, the discipline of adolescent brain studies learned to do some more-complex thinking of its own. A few researchers began to view recent brain and genetic findings in a brighter, more flattering light, one distinctly colored by evolutionary theory. The resulting account of the adolescent brain—call it the adaptive-adolescent story—casts the teen less as a rough draft than as an exquisitely sensitive, highly adaptable creature wired almost perfectly for the job of moving from the safety of home into the complicated world outside.

This view will likely sit better with teens. More important, it sits better with biology's most fundamental principle, that of natural selection. Selection is hell on dysfunctional traits. If adolescence is essentially a collection of them—angst, idiocy, and haste; impulsiveness, selfishness, and reckless bumbling—then how did those traits survive selection? They couldn't—not if they were the period's most fundamental or consequential features.

The answer is that those troublesome traits don't really characterize adolescence; they're just what we notice most because they annoy us or put our children in danger. As B. J. Casey, a neuroscientist at Weill Cornell Medical College who has spent nearly a decade applying brain and genetic studies to our understanding of adolescence, puts it, "We're so used to seeing adolescence as a problem. But the more we learn about what really makes this period unique, the more adolescence starts to seem like a highly functional, even adaptive period. It's exactly what you'd need to do the things you have to do then."

To see past the distracting, dopey teenager and glimpse the adaptive adolescent within, we should look not at specific, sometimes startling, behaviors, such as skateboarding down stairways or dating fast company, but at the broader traits that underlie those acts.

Let's start with the teen's love of the thrill. We all like new and exciting things, but we never value them more highly than we do during adolescence. Here we hit a high in what behavioral scientists call sensation seeking: the hunt for the neural buzz, the jolt of the unusual or unexpected.

Seeking sensation isn't necessarily impulsive. You might plan a sensation-seeking experience—a skydive or a fast drive—quite deliberately, as my son did. Impulsivity generally drops throughout life, starting at about age 10, but this love of the thrill peaks at around age 15. And although sensation seeking can lead to dangerous behaviors, it can also generate positive ones: The urge to meet more people, for instance, can create a wider circle of friends, which generally makes us healthier, happier, safer, and more successful.

This upside probably explains why an openness to the new, though it can sometimes kill the cat, remains a highlight of adolescent development. A love of novelty leads directly to useful experience. More broadly, the hunt for sensation provides the inspiration needed to "get you out of the house" and into new terrain, as Jay Giedd, a pioneering researcher in teen brain development at NIH, puts it.

Also peaking during adolescence (and perhaps aggrieving the ancientry the most) is risk-taking. We court risk more avidly as teens than at any other time. This shows reliably in the lab, where teens take more chances in controlled experiments involving everything from card games to simulated driving. And it shows in real life, where the period from roughly 15 to 25 brings peaks in all sorts of risky ventures and ugly outcomes. This age group dies of accidents of almost every sort (other than work accidents) at high rates. Most long-term drug or alcohol abuse starts during adolescence, and even people who later drink responsibly often drink too much as teens. Especially in cultures where teenage driving is common, this takes a gory toll: In the U.S., one in three teen deaths is from car crashes, many involving alcohol.

Are these kids just being stupid? That's the conventional explanation: They're not thinking, or by the work-in-progress model, their puny developing brains fail them.

Yet these explanations don't hold up. As Laurence Steinberg, a developmental psychologist specializing in adolescence at Temple University, points out, even 14- to 17-year-olds—the biggest risk takers—use the same basic cognitive strategies that adults do, and they usually reason their way through problems just as well as adults. Contrary to popular belief, they also fully recognize they're mortal. And, like adults, says Steinberg, "teens actually overestimate risk."

So if teens think as well as adults do and recognize risk just as well, why do they take more chances? Here, as elsewhere, the problem lies less in what teens lack compared with adults than in what they have more of. Teens take more risks not because they don't understand the dangers but because they weigh risk versus reward differently: In situations where risk can get them something they want, they value the reward more heavily than adults do.

A video game Steinberg uses draws this out nicely. In the game, you try to drive across town in as little time as possible. Along the way you encounter several traffic lights. As in real life, the traffic lights sometimes turn from green to yellow as you approach them, forcing a quick go-or-stop decision. You save time—and score more points—if you drive through before the light turns red. But if you try to drive through the red and don't beat it, you lose even more time than you would have if you had stopped for it. Thus the game rewards you for taking a certain amount of risk but punishes you for taking too much.

When teens drive the course alone, in what Steinberg calls the emotionally "cool" situation of an empty room, they take risks at about the same rates that adults do. Add stakes that the teen cares about, however, and the situation changes. In this case Steinberg added friends: When he brought a teen's friends into the room to watch, the teen would take twice as many risks, trying to gun it through lights he'd stopped for before. The adults, meanwhile, drove no differently with a friend watching.

To Steinberg, this shows clearly that risk-taking rises not from puny thinking but from a higher regard for reward.

"They didn't take more chances because they suddenly downgraded the risk," says Steinberg. "They did so because they gave more weight to the payoff."

Researchers such as Steinberg and Casey believe this risk-friendly weighing of cost versus reward has been selected for because, over the course of human evolution, the willingness to take risks during this period of life has granted an adaptive edge. Succeeding often requires moving out of the home and into less secure situations. "The more you seek novelty and take risks," says Baird, "the better you do." This responsiveness to reward thus works like the desire for new sensation: It gets you out of the house and into new turf.

As Steinberg's driving game suggests, teens respond strongly to social rewards. Physiology and evolutionary theory alike offer explanations for this tendency. Physiologically, adolescence brings a peak in the brain's sensitivity to dopamine, a neurotransmitter that appears to prime and fire reward circuits and aids in learning patterns and making decisions. This helps explain the teen's quickness of learning and extraordinary receptivity to reward—and his keen, sometimes melodramatic reaction to success as well as defeat.

The teen brain is similarly attuned to oxytocin, another neural hormone, which (among other things) makes social connections in particular more rewarding. The neural networks and dynamics associated with general reward and social interactions overlap heavily. Engage one, and you often engage the other. Engage them during adolescence, and you light a fire.

This helps explain another trait that marks adolescence: Teens prefer the company of those their own age more than ever before or after. At one level, this passion for same-age peers merely expresses in the social realm the teen's general attraction to novelty: Teens offer teens far more novelty than familiar old family does.

Yet teens gravitate toward peers for another, more powerful reason: to invest in the future rather than the past. We enter a world made by our parents. But we will live most of our lives, and prosper (or

not) in a world run and remade by our peers. Knowing, understanding, and building relationships with them bears critically on success. Socially savvy rats or monkeys, for instance, generally get the best nesting areas or territories, the most food and water, more allies, and more sex with better and fitter mates. And no species is more intricately and deeply social than humans are.

This supremely human characteristic makes peer relations not a sideshow but the main show. Some brain-scan studies, in fact, suggest that our brains react to peer exclusion much as they respond to threats to physical health or food supply. At a neural level, in other words, we perceive social rejection as a threat to existence. Knowing this might make it easier to abide the hysteria of a 13-year-old deceived by a friend or the gloom of a 15-year-old not invited to a party. These people! we lament. They react to social ups and downs as if their fates depended upon them! They're right. They do.

Excitement, novelty, risk, the company of peers. These traits may seem to add up to nothing more than doing foolish new stuff with friends. Look deeper, however, and you see that these traits that define adolescence make us more adaptive, both as individuals and as a species. That's doubtless why these traits, broadly defined, seem to show themselves in virtually all human cultures, modern or tribal. They may concentrate and express themselves more starkly in modern Western cultures, in which teens spend so much time with each other. But anthropologists have found that virtually all the world's cultures recognize adolescence as a distinct period in which adolescents prefer novelty, excitement, and peers. This near-universal recognition sinks the notion that it's a cultural construct.

Culture clearly shapes adolescence. It influences its expression and possibly its length. It can magnify its manifestations. Yet culture does not create adolescence. The period's uniqueness rises from genes and developmental processes that have been selected for over thousands of generations because they play an amplified role during this key transitional period: producing a creature optimally primed to leave a safe home and move into unfamiliar territory.

The move outward from home is the most difficult thing that humans do, as well as the most critical—not just for individuals but for a species that has shown an unmatched ability to master challenging new environments. In scientific terms, teenagers can be a pain in the ass. But they are quite possibly the most fully, crucially adaptive human beings around. Without them, humanity might not have so readily spread across the globe.

This adaptive-adolescence view, however accurate, can be tricky to come to terms with—the more so for parents dealing with teens in their most trying, contrary, or flat-out scary moments. It's reassuring to recast worrisome aspects as signs of an organism learning how to negotiate its surroundings. But natural selection swings a sharp edge, and the teen's sloppier moments can bring unbearable consequences. We may not run the risk of being killed in ritualistic battles or being eaten by leopards, but drugs, drinking, driving, and crime take a mighty toll. My son lives, and thrives, sans car, at college. Some of his high school friends, however, died during their driving experiments. Our children wield their adaptive plasticity amid small but horrific risks.

We parents, of course, often stumble too, as we try to walk the blurry line between helping and hindering our kids as they adapt to adulthood. The United States spends about a billion dollars a year on programs to counsel adolescents on violence, gangs, suicide, sex, substance abuse, and other potential pitfalls. Few of them work.

Yet we can and do help. We can ward off some of the world's worst hazards and nudge adolescents toward appropriate responses to the rest. Studies show that when parents engage and guide their teens with a light but steady hand, staying connected but allowing independence, their kids generally do much better in life. Adolescents want to learn primarily, but not entirely, from their friends. At some level and at some times (and it's the parent's job to spot when), the teen recognizes that the parent can

offer certain kernels of wisdom—knowledge valued not because it comes from parental authority but because it comes from the parent's own struggles to learn how the world turns. The teen rightly perceives that she must understand not just her parents' world but also the one she is entering. Yet if allowed to, she can appreciate that her parents once faced the same problems and may remember a few things worth knowing.

Meanwhile, in times of doubt, take inspiration in one last distinction of the teen brain—a final key to both its clumsiness and its remarkable adaptability. This is the prolonged plasticity of those late-developing frontal areas as they slowly mature. As noted earlier, these areas are the last to lay down the fatty myelin insulation—the brain's white matter—that speeds transmission. And at first glance this seems like bad news: If we need these areas for the complex task of entering the world, why aren't they running at full speed when the challenges are most daunting?

The answer is that speed comes at the price of flexibility. While a myelin coating greatly accelerates an axon's bandwidth, it also inhibits the growth of new branches from the axon. According to Douglas Fields, an NIH neuroscientist who has spent years studying myelin, "This makes the period when a brain area lays down myelin a sort of crucial period of learning—the wiring is getting upgraded, but once that's done, it's harder to change."

The window in which experience can best rewire those connections is highly specific to each brain area. Thus the brain's language centers acquire their insulation most heavily in the first 13 years, when a child is learning language. The completed insulation consolidates those gains—but makes further gains, such as second languages, far harder to come by.

So it is with the forebrain's myelination during the late teens and early 20s. This delayed completion—a withholding of readiness—heightens flexibility just as we confront and enter the world that we will face as adults. This long, slow, back-to-front developmental wave, completed only in the mid-20s, appears to be a uniquely human adaptation. It may be one of our most consequential. It can seem a bit crazy that we humans don't wise up a bit earlier in life. But if we smartened up sooner, we'd end up dumber.

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.

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

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

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.

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

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

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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LITERATURE CITED

Belter R, Grisso T. 1984. Children's recognition of rights violations in counseling. *Prof. Psychol. Res. Pract.* 15:899–910

Berg W, Byrd D. 2002. The Tower of London spatial problem solving task: enhancing clinical and research implementation. *J. Exp. Clin. Neuropsychol.* 25:586–604

Bishop D, Frazier C. 2000. Consequences of transfer. In *The Changing Borders of Juvenile Justice*, ed. J Fagan, F Zimring, pp. 227–77. Chicago: Univ. Chicago Press

Casey BJ, Getz S, Galvan A. 2008. The adolescent brain. *Dev. Rev.* 28:62–77

Cauffman E, Shulman E, Claus E, Banich M, Steinberg L, et al. 2008. Responding to reward versus punishment: how adolescents differ from adults in performance on the Iowa Gambling Task. Dept. Psychol. Social Behav., Univ. Calif., Irvine. Manuscr. under review

Cauffman E, Steinberg L, Piquero A. 2005. Psychological, neuropsychological, and psychophysiological correlates of serious antisocial behavior in adolescence: the role of self-control. *Criminology* 43:133–76

Collins WA, Steinberg L. 2006. Adolescent development in interpersonal context. In *Social, Emotional, and Personality Development. Handbook of Child Psychology*, ed. W Damon, R Lerner, N Eisenberg, pp. 1003–67. New York: Wiley

Conklin H, Luciana M, Hooper C, Yarger R. 2007. Working memory performance in typically developing children and adolescents: behavioral evidence of protracted frontal lobe development. *Dev. Neuropsychol.* 31:103–28

Cooper D. 1997. Juveniles' understanding of trial-related information: Are they competent defendants? *Behav. Sci. Law* 15:167–80

Crone EA, Bunge SA, Latenstein H, Van Der Molen MW. 2005. Characterization of children's decision making: sensitivity to punishment frequency, not task complexity. *Child Neuropsychol.* 11:245–63

Crone EA, Van Der Molen MW. 2004. Developmental changes in real life decision making: performance on a gambling task previously shown to depend on the ventromedial prefrontal cortex. *Dev. Neuropsychol.* 25:251–79

Dahl R. 2001. Affect regulation, brain development, and behavioral/emotional health in adolescence. *CNS Spectr.* 6:1–12

Dahl R. 2004. Adolescent brain development: a period of vulnerabilities and opportunities. *Ann. N. Y. Acad. Sci.* 1021:1–22

Fagan J. 1996. The comparative impacts of juvenile and criminal court sanctions on adolescent felony offenders. *Law Policy Rev.* 18:77–119

Fagan J. 2008. Juvenile crime and criminal justice: resolving border disputes. *Fut. Child.* 18(2):81–118

Feld BC. 1993. Criminalizing the American juvenile court. *Crime Just.* 17:197–280

Galvan A, Hare T, Voss H, Glover G, Casey BJ. 2007. Risk-taking and the adolescent brain: Who is at risk? *Dev. Sci.* 10:F8–14

Gardner M, Steinberg L. 2005. Peer influence on risk-taking, risk preference, and risky decision-making in adolescence and adulthood: an experimental study. *Dev. Psychol.* 41:625–35

Gardner W. 1993. A life-span rational choice theory of risk taking. In *Adolescent Risk Taking*, ed. N Bell, R Bell, pp. 66–83. Newbury Park, CA: Sage

Greene A. 1986. Future time perspective in adolescence: the present of things future revisited. *J. Youth Adolesc.* 15:99–113

Greenwood P. 2006. *Changing Lives: Delinquency Prevention as Crime Control Policy*. Chicago: Univ. Chicago Press

Grisso T. 1981. *Juveniles' Waiver of Rights: Legal and Psychological Competence*. New York: Plenum

Grisso T, Vierling L. 1978. Minors' consent to treatment: a developmental perspective. *Prof. Psychol.* 9:412–26

Grisso T, Steinberg L, Woolard J, Cauffman E, Scott E, et al. 2003. Juveniles' competence to stand trial: a comparison of adolescents' and adults' capacities as trial defendants. *Law Hum. Behav.* 27:333–63

Grosbras M, Jansen M, Leonard G, McIntosh A, Osswald K, et al. 2007. Neural mechanisms of resistance to peer influence in early adolescence. *J. Neurosci.* 27:8040–45

Gustafson K, McNamara J. 1987. Confidentiality with minor clients: issues and guidelines for therapists. *Prof. Psychol. Res. Pract.* 18:503–8

Hale S. 1990. A global developmental trend in cognitive processing speed. *Child Dev.* 61:653–63

Hooper C, Luciana M, Conklin H, Yarger R. 2004. Adolescents' performance on the Iowa Gambling Task: implications for the development of decision making and ventromedial prefrontal cortex. *Dev. Psychol.* 40:1148–58

Kail R. 1997. Processing time, imagery, and spatial memory. *J. Exp. Child Psychol.* 64:67–78

Keating D. 2004. Cognitive and brain development. In *Handbook of Adolescent Psychology*, ed. R Lerner, L Steinberg, pp. 45–84. New York: Wiley. 2nd ed.

Provides an excellent summary of research on the impact of trying juveniles as adults on adolescents' behavior, mental health, and recidivism.

Furnishes a comprehensive analysis of the effectiveness of various approaches to preventing and treating juvenile delinquency.

Landmark empirical study that demonstrates that in comparison to adults, individuals under 16 are more likely to be incompetent to stand trial.

Krisberg B, Austin J. 1993. *Reinventing Juvenile Justice*. Newbury Park, CA: Sage
Kuhn D. 2009. Adolescent thinking. See Lerner & Steinberg 2009. In press
Lerner R, Steinberg L, eds. 2009. *Handbook of Adolescent Psychology*. New York: Wiley. 3rd ed. In press
Leshem R, Glicksohn J. 2007. The construct of impulsivity revisited. *Personal. Individ. Differ.* 43:681–91
Lipsey M. 1995. What do we learn from 400 research studies on the effectiveness of treatment with juvenile delinquents? In *What Works? Reducing Reoffending*, ed. J McGuire, pp. 63–78. New York: Wiley
Lipsey M. 1999. Can rehabilitative programs reduce the recidivism of young offenders? An inquiry into the effectiveness of practical programs. *Va. J. Soc. Policy Law* 6:611–41
Luna B, Thulborn K, Munoz D, Merriam E, Garver K, et al. 2001. Maturation of widely distributed brain function subserves cognitive development. *Neuroimage* 13:786–93
Mack J. 1909. The juvenile court. *Harv. Law Rev.* 23:104–22
Millstein S, Halpern-Felsher B. 2002. Perceptions of risk and vulnerability. *J. Adolesc. Health* 31S:10–27
Moffitt T. 1993. Adolescence-limited and life-course persistent antisocial behavior: a developmental taxonomy. *Psychol. Rev.* 100:674–701
Mulvey E, Leistico A. 2008. Improving professional judgments of risk and amenability in juvenile justice. *Fut. Child.* 18(2):35–58
Nurmi J. 1991. How do adolescents see their future? A review of the development of future orientation and planning. *Dev. Rev.* 11:1–59
Overton W. 1990. Competence and procedures: constraints on the development of logical reasoning. In *Reasoning, Necessity, and Logic: Developmental Perspectives*, ed. W Overton, pp. 1–32. Hillsdale, NJ: Erlbaum

Provides a legal analysis of how the justice system might best take the developmental incompetence of juveniles into account. Argues that a lower standard of competence should be used in juvenile than in criminal court.

Paus T. 2005. Mapping brain maturation and cognitive development during adolescence. *Trends Cogn. Sci.* 9:60–68
Paus T, Toro R, Leonard G, Lerner J, Lerner R, et al. 2008. Morphological properties of the action-observation cortical network in adolescents with low and high resistance to peer influence. *Soc. Neurosci.* In press
Peterson-Badali M, Abramovitch R. 1993. Grade related changes in young people's reasoning about plea decisions. *Law Hum. Behav.* 17:537–52
Piquero A, Farrington D, Blumstein A. 2003. The criminal career paradigm: background and recent developments. *Crime Just.* 30:359–506
Platt A. 1977. *The Child Savers: The Invention of Delinquency*. Chicago: Univ. Chicago Press. 2nd ed.
Roper v. Simmons, 541 U.S. 1040 2005

Calls for juvenile justice reform based on the scientific study of adolescent development. Supplies useful summaries of literatures on adolescents' criminal culpability, competence to stand trial, and response to intervention.

Scott E, Grisso T. 2005. Developmental incompetence, due process, and juvenile justice policy. *N. C. Law Rev.* 83:793–846
Scott E, Reppucci N, Woolard J. 1995. Evaluating adolescent decision making in legal contexts. *Law Hum. Behav.* 19:221–44
Scott E, Steinberg L. 2008. *Rethinking Juvenile Justice*. Cambridge, MA: Harvard Univ. Press
Sisk C, Foster D. 2004. The neural basis of puberty and adolescence. *Nat. Neurosci.* 7:1040–47
Sisk C, Zehr J. 2005. Pubertal hormones organize the adolescent brain and behavior. *Front. Neuroendocrinol.* 26:163–74
Smetana J, Campione-Barr N, Metzger A. 2006. Adolescent development in interpersonal and societal contexts. *Annu. Rev. Psychol.* 57:255–84
Steinberg L. 2004. Risk-taking in adolescence: What changes, and why? *Ann. N. Y. Acad. Sci.* 1021:51–58
Steinberg L. 2007. Risk-taking in adolescence: new perspectives from brain and behavioral science. *Curr. Dir. Psychol. Sci.* 16:55–59

Discusses how brain development in adolescence affects risk taking and reckless behavior, in which the heightened vulnerability of middle adolescence is highlighted.

Steinberg L. 2008. A social neuroscience perspective on adolescent risk-taking. *Dev. Rev.* 28:78–106
Steinberg L, Albert D, Cauffman E, Banich M, Graham S, Woolard J. 2008a. Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: evidence for a dual systems model. *Dev. Psychol.* In press
Steinberg L, Cauffman E. 1996. Maturity of judgment in adolescence: psychosocial factors in adolescent decisionmaking. *Law Hum. Behav.* 20:249–72
Steinberg L, Cauffman E, Woolard J, Graham S, Banich M. 2008b. Are adolescents less mature than adults? Minors' access to abortion, the juvenile death penalty, and the alleged APA "flip-flop." Manuscript under review. Dept. Psychol., Temple Univ. In press

Steinberg L, Chung H, Little M. 2004. Reentry of young offenders from the justice system: a developmental perspective. *Youth Violence Juv. Just.* 1:21–38

Steinberg L, Graham S, O'Brien L, Woolard J, Cauffman E, Banich M. 2008c. Age differences in future orientation and delay discounting. *Child Dev.* In press

Steinberg L, Monahan K. 2007. Age differences in resistance to peer influence. *Dev. Psychol.* 43:1531–43

Steinberg L, Schwartz R. 2000. Developmental psychology goes to court. In *Youth on Trial: A Developmental Perspective on Juvenile Justice*, ed. T Grisso, R Schwartz, pp. 9–31. Chicago: Univ. Chicago Press

Steinberg L, Scott E. 2003. Less guilty by reason of adolescence: developmental immaturity, diminished responsibility, and the juvenile death penalty. *Am. Psychol.* 58:1009–18

Teicher M, Andersen S, Hostetter J. 1995. Evidence for dopamine receptor pruning between adolescence and adulthood in striatum but not nucleus accumbens. *Dev. Brain Res.* 89:167–72

Weithorn L, Campbell S. 1982. The competency of children and adolescents to make informed treatment decisions. *Child Dev.* 53:1589–98

Zimring F. 1998. *American Youth Violence*. New York: Oxford Univ. Press

Discusses why adolescents, by virtue of developmental immaturity, are inherently less culpable than adults. Cited multiple times by U.S. Supreme Court in its decision to abolish juvenile death penalty.

Risk Taking in Adolescence

New Perspectives From Brain and Behavioral Science

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ABSTRACT—*Trying to understand why adolescents and young adults take more risks than younger or older individuals do has challenged psychologists for decades. Adolescents' inclination to engage in risky behavior does not appear to be due to irrationality, delusions of invulnerability, or ignorance. This paper presents a perspective on adolescent risk taking grounded in developmental neuroscience. According to this view, the temporal gap between puberty, which impels adolescents toward thrill seeking, and the slow maturation of the cognitive-control system, which regulates these impulses, makes adolescence a time of heightened vulnerability for risky behavior. This view of adolescent risk taking helps to explain why educational interventions designed to change adolescents' knowledge, beliefs, or attitudes have been largely ineffective, and suggests that changing the contexts in which risky behavior occurs may be more successful than changing the way adolescents think about risk.*

KEYWORDS—*adolescence; decision making; risk taking; brain development*

Adolescents and college-age individuals take more risks than children or adults do, as indicated by statistics on automobile crashes, binge drinking, contraceptive use, and crime; but trying to understand why risk taking is more common during adolescence than during other periods of development has challenged psychologists for decades (Steinberg, 2004). Numerous theories to account for adolescents' greater involvement in risky behavior have been advanced, but few have withstood empirical scrutiny (but see Reyna & Farley, 2006, for a discussion of some promising approaches).

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FALSE LEADS IN RISK-TAKING RESEARCH

Systematic research does not support the stereotype of adolescents as irrational individuals who believe they are invulnerable and who are unaware, inattentive to, or unconcerned about the potential harms of risky behavior. In fact, the logical-reasoning abilities of 15-year-olds are comparable to those of adults, adolescents are no worse than adults at perceiving risk or estimating their vulnerability to it (Reyna & Farley, 2006), and increasing the salience of the risks associated with making a potentially dangerous decision has comparable effects on adolescents and adults (Millstein & Halpern-Felsher, 2002). Most studies find few age differences in individuals' evaluations of the risks inherent in a wide range of dangerous behaviors, in judgments about the seriousness of the consequences that might result from risky behavior, or in the ways that the relative costs and benefits of risky activities are evaluated (Beyth-Marom, Austin, Fischoff, Palmgren, & Jacobs-Quadrel, 1993).

Because adolescents and adults reason about risk in similar ways, many researchers have posited that age differences in actual risk taking are due to differences in the information that adolescents and adults use when making decisions. Attempts to reduce adolescent risk taking through interventions designed to alter knowledge, attitudes, or beliefs have proven remarkably disappointing, however (Steinberg, 2004). Efforts to provide adolescents with information about the risks of substance use, reckless driving, and unprotected sex typically result in improvements in young people's thinking about these phenomena but seldom change their actual behavior. Generally speaking, reductions in adolescents' health-compromising behavior are more strongly linked to changes in the contexts in which those risks are taken (e.g., increases in the price of cigarettes, enforcement of graduated licensing programs, more vigorously implemented policies to interdict drugs, or condom distribution programs) than to changes in what adolescents know or believe.

The failure to account for age differences in risk taking through studies of reasoning and knowledge stymied researchers for some time. Health educators, however, have been undaunted, and they have continued to design and offer interventions qof unproven effectiveness, such as Drug Abuse Resistance

Education (DARE), driver's education, or abstinence-only sex education.

A NEW PERSPECTIVE ON RISK TAKING

In recent years, owing to advances in the developmental neuroscience of adolescence and the recognition that the conventional decision-making framework may not be the best way to think about adolescent risk taking, a new perspective on the subject has emerged (Steinberg, 2004). This new view begins from the premise that risk taking in the real world is the product of both logical reasoning and psychosocial factors. However, unlike logical-reasoning abilities, which appear to be more or less fully developed by age 15, psychosocial capacities that improve decision making and moderate risk taking—such as impulse control, emotion regulation, delay of gratification, and resistance to peer influence—continue to mature well into young adulthood (Steinberg, 2004; see Fig. 1). Accordingly, psychosocial immaturity in these respects during adolescence may undermine what otherwise might be competent decision making. The conclusion drawn by many researchers, that adolescents are as competent decision makers as adults are, may hold true only under conditions where the influence of psychosocial factors is minimized.

Evidence From Developmental Neuroscience

Advances in developmental neuroscience provide support for this new way of thinking about adolescent decision making. It appears that heightened risk taking in adolescence is the product of the interaction between two brain networks. The first is a socioemotional network that is especially sensitive to social and emotional stimuli, that is particularly important for reward processing, and that is remodeled in early adolescence by the hormonal changes of puberty. It is localized in limbic and paralimbic areas of the brain, an interior region that includes the amygdala, ventral striatum, orbitofrontal cortex, medial prefrontal cortex, and superior temporal sulcus. The second network is a cognitive-control network that subserves executive functions such as planning, thinking ahead, and self-regulation, and that matures gradually over the course of adolescence and young adulthood largely independently of puberty (Steinberg, 2004). The cognitive-control network mainly consists of outer regions of the brain, including the lateral prefrontal and parietal cortices and those parts of the anterior cingulate cortex to which they are connected.

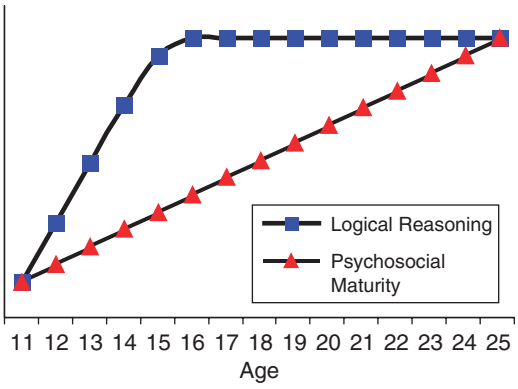

Fig. 1. Hypothetical graph of development of logical reasoning abilities versus psychosocial maturation. Although logical reasoning abilities reach adult levels by age 16, psychosocial capacities, such as impulse control, future orientation, or resistance to peer influence, continue to develop into young adulthood.

In many respects, risk taking is the product of a competition between the socioemotional and cognitive-control networks (Drevets & Raichle, 1998), and adolescence is a period in which the former abruptly becomes more assertive (i.e., at puberty) while the latter gains strength only gradually, over a longer period of time. The socioemotional network is not in a state of constantly high activation during adolescence, though. Indeed, when the socioemotional 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. In the presence of peers or under conditions of emotional arousal, however, the socioemotional network becomes sufficiently activated to diminish the regulatory effectiveness of the cognitive-control network. Over the course of adolescence, the cognitive-control network matures, so that by adulthood, even under conditions of heightened arousal in the socioemotional network, inclinations toward risk taking can be modulated.

It is important to note that mechanisms underlying the processing of emotional information, social information, and reward are closely interconnected. Among adolescents, the regions that are activated during exposure to social and emotional stimuli overlap considerably with regions also shown to be sensitive to variations in reward magnitude (cf. Galvan, et al., 2005; Nelson, Leibenluft, McClure, & Pine, 2005). This finding may be relevant to understanding why so much adolescent risk taking—like drinking, reckless driving, or delinquency—occurs in groups (Steinberg, 2004). Risk taking may be heightened in adolescence because teenagers spend so much time with their peers, and the mere presence of peers makes the rewarding aspects of risky situations more salient by activating the same circuitry that is activated by exposure to nonsocial rewards when individuals are alone.

The competitive interaction between the socioemotional and cognitive-control networks has been implicated in a wide range of decision-making contexts, including drug use, social-decision processing, moral judgments, and the valuation of alternative rewards/costs (e.g., Chambers, Taylor, & Potenza, 2003). In all of these contexts, risk taking is associated with relatively greater activation of the socioemotional network. For example, individuals' preference for smaller immediate rewards over

larger delayed rewards is associated with relatively increased activation of the ventral striatum, orbitofrontal cortex, and medial prefrontal cortex—all regions linked to the socioemotional network—presumably because immediate rewards are especially emotionally arousing (consider the difference between how you might feel if a crisp $100 bill were held in front of you versus being told that you will receive $150 in 2 months). In contrast, regions implicated in cognitive control are engaged equivalently across decision conditions (McClure, Laibson, Loewenstein, & Cohen, 2004). Similarly, studies show that increased activity in regions of the socioemotional network is associated with the selection of comparatively risky (but potentially highly rewarding) choices over more conservative ones (Ernst et al., 2005).

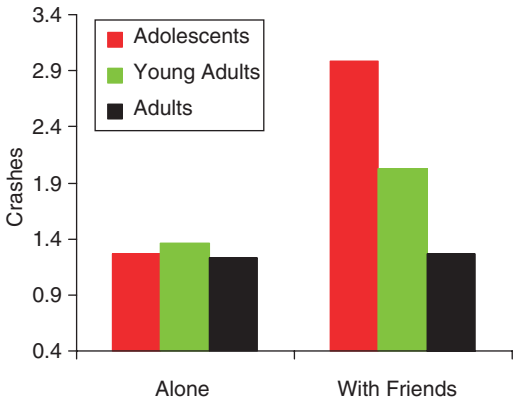

Fig. 2. Risk taking of adolescents, young adults, and adults during a video driving game, when playing alone and when playing with friends. Adapted from Gardner & Steinberg (2004).

Evidence From Behavioral Science

Three lines of behavioral evidence are consistent with this account. First, studies of susceptibility to antisocial peer influence show that vulnerability to peer pressure increases between preadolescence and mid-adolescence, peaks in mid-adolescence—presumably when the imbalance between the sensitivity to socioemotional arousal (which has increased at puberty) and capacity for cognitive control (which is still immature) is greatest—and gradually declines thereafter (Steinberg, 2004). Second, as noted earlier, studies of decision making generally show no age differences in risk processing between older adolescents and adults when decision making is assessed under conditions likely associated with relatively lower activation of brain systems responsible for emotion, reward, and social processing (e.g., the presentation of hypothetical decision-making dilemmas to individuals tested alone under conditions of low emotional arousal; Millstein, & Halpern-Felsher, 2002). Third, the presence of peers increases risk taking substantially among teenagers, moderately among college-age individuals, and not at all among adults, consistent with the notion that the development of the cognitive-control network is gradual and extends beyond the teen years. In one of our lab's studies, for instance, the presence of peers more than doubled the number of risks teenagers took in a video driving game and increased risk taking by 50% among college undergraduates but had no effect at all among adults (Gardner & Steinberg, 2005; see Fig. 2). In adolescence, then, not only is more merrier—it is also riskier.

What Changes During Adolescence?

Studies of rodents indicate an especially significant increase in reward salience (i.e., how much attention individuals pay to the magnitude of potential rewards) around the time of puberty (Spear, 2000), consistent with human studies showing that increases in sensation seeking occur relatively early in adolescence and are correlated with pubertal maturation but not chronological age (Steinberg, 2004). Given behavioral findings indicating relatively greater reward salience among adolescents than adults in decision-making tasks, there is reason to speculate that, when presented with risky situations that have both potential rewards and potential costs, adolescents may be more sensitive than adults to variation in rewards but comparably sensitive (or perhaps even less sensitive) to variation in costs (Ernst et al., 2005).

It thus appears that the brain system that regulates the processing of rewards, social information, and emotions is becoming more sensitive and more easily aroused around the time of puberty. What about its sibling, the cognitive-control system? Regions making up the cognitive-control network, especially prefrontal regions, continue to exhibit gradual changes in structure and function during adolescence and early adulthood (Casey, Tottenham, Liston, & Durston, 2005). Much publicity has been given to the finding that synaptic pruning (the selective elimination of seldom-used synapses) and myelination (the development of the fatty sheaths that "insulate" neuronal circuitry)—both of which increase the efficiency of information processing—continue to occur in the prefrontal cortex well into the early 20s. But frontal regions also become more integrated with other brain regions during adolescence and early adulthood, leading to gradual improvements in many aspects of cognitive control such as response inhibition; this integration may be an even more important change than changes within the frontal region itself. 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—have shown that adolescents tend to recruit the cognitive-control network less broadly than do adults, perhaps overtaxing the capacity of the more limited number of regions they activate (Luna et al., 2001).

In essence, one of the reasons the cognitive-control system of adults is more effective than that of adolescents is that adults' brains distribute its regulatory responsibilities across a wider network of linked components. This lack of cross-talk across brain regions in adolescence results not only in individuals

acting on gut feelings without fully thinking (the stereotypic portrayal of teenagers) but also in thinking too much when gut feelings ought to be attended to (which teenagers also do from time to time). In one recent study, when asked whether some obviously dangerous activities (e.g., setting one's hair on fire) were "good ideas," adolescents took significantly longer than adults to respond to the questions and activated a less narrowly distributed set of cognitive-control regions (Baird, Fugelsang, & Bennett, 2005). This was not the case when the queried activities were not dangerous ones, however (e.g., eating salad).

The fact that maturation of the socioemotional network appears to be driven by puberty, whereas the maturation of the cognitive-control network does not, raises interesting questions about the impact—at the individual and at the societal levels—of early pubertal maturation on risk-taking. We know that there is wide variability among individuals in the timing of puberty, due to both genetic and environmental factors. We also know that there has been a significant drop in the age of pubertal maturation over the past 200 years. To the extent that the temporal disjunction between the maturation of the socioemotional system and that of the cognitive-control system contributes to adolescent risk taking, we would expect to see higher rates of risk taking among early maturers and a drop over time in the age of initial experimentation with risky behaviors such as sexual intercourse or drug use. There is evidence for both of these patterns (Collins & Steinberg, 2006; Johnson & Gerstein, 1998).

IMPLICATIONS FOR PREVENTION

What does this mean for the prevention of unhealthy risk taking in adolescence? Given extant research suggesting that it is not the way adolescents think or what they don't know or understand that is the problem, a more profitable strategy than attempting to change how adolescents view risky activities might be to focus on limiting opportunities for immature judgment to have harmful consequences. 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 (often more than one of these 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 strategies aimed at making adolescents wiser, less impulsive, or less shortsighted. Some things just take time to develop, and, like it or not, 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 that can or ought to be done to either attenuate or delay the shift in reward sensitivity that takes place at puberty. It may be possible to accelerate the maturation of self-regulatory competence, but no research has examined whether this is possible. In light of studies showing familial influences on psychosocial maturity in adolescence, understanding how contextual factors influence the development of self-regulation and knowing the neural underpinnings of these processes should be a high priority for those interested in the well-being of young people.

Recommended Reading

Casey, B.J., Tottenham, N., Liston, C., & Durston, S. (2005). (See References)

Johnson, R., & Gerstein, D. (1998). (See References)

Nelson, E., Leibenluft, E., McClure, E., & Pine, D. (2005). (See References)

Spear, P. (2000). (See References)

Steinberg, L. (2004). (See References)

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REFERENCES

Baird, A., Fugelsang, J., & Bennett, C. (2005, April). *"What were you thinking?": An fMRI study of adolescent decision making*. Poster presented at the annual meeting of the Cognitive Neuroscience Society, New York.

Beyth-Marom, R., Austin, L., Fischoff, B., Palmgren, C., & Jacobs-Quadrel, M. (1993). Perceived consequences of risky behaviors: Adults and adolescents. *Developmental Psychology*, *29*, 549–563.

Casey, B.J., Tottenham, N., Liston, C., & Durston, S. (2005). Imaging the developing brain: What have we learned about cognitive development? *Trends in Cognitive Science*, *9*, 104–110.

Chambers, R.A., Taylor, J.R., & Potenza, M.N. (2003). Developmental neurocircuitry of motivation in adolescence: A critical period of addiction vulnerability. *American Journal of Psychiatry*, *160*, 1041–1052.

Collins, W.A., & Steinberg, L. (2006). Adolescent development in interpersonal context. In W. Damon & R. Lerner (Series Eds.) & N. Eisenberg (Vol. Ed.), *Handbook of Child Psychology: Social, emotional, and personality development* (Vol. 3, pp. 1003–1067). New York: Wiley.

Drevets, W.C., & Raichle, M.E. (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: Implications for interactions between emotion and cognition. *Cognition and Emotion*, *12*, 353–385.

Ernst, M., Jazbec, S., McClure, E.B., Monk, C.S., Blair, R.J.R., Leibenluft, E., & Pine, D.S. (2005). Amygdala and nucleus accumbens activation in response to receipt and omission of gains in adults and adolescents. *Neuroimage*, *25*, 1279–1291.

Galvan, A., Hare, T., Davidson, M., Spicer, J., Glover, G., & Casey, B.J. (2005). The role of ventral frontostriatal circuitry in reward-based learning in humans. *Journal of Neuroscience*, *25*, 8650–8656.

Gardner, M., & Steinberg, L. (2005). Peer influence on risk-taking, risk preference, and risky decision-making in adolescence and

adulthood: An experimental study. *Developmental Psychology*, *41*, 625–635.

Johnson, R., & Gerstein, D. (1998). Initiation of use of alcohol, cigarettes, marijuana, cocaine, and other substances in US birth cohorts since 1919. *American Journal of Public Health*, *88*, 27–33.

Luna, B., Thulborn, K.R., Munoz, D.P., Merriam, E.P., Garver, K.E., Minshew, N.J., et al. (2001). Maturation of widely distributed brain function subserves cognitive development. *Neuroimage*, *13*, 786–793.

McClure, S.M., Laibson, D.I., Loewenstein, G., & Cohen, J.D. (2004). Separate neural systems value immediate and delayed monetary rewards. *Science*, *306*, 503–507.

Millstein, S.G., & Halpern-Felsher, B.L. (2002). Perceptions of risk and vulnerability. *Journal of Adolescent Health*, *31S*, 10–27.

Nelson, E., Leibenluft, E., McClure, E., & Pine, D. (2005). The social re-orientation of adolescence: A neuroscience perspective on the process and its relation to psychopathology. *Psychological Medicine*, *35*, 163–174.

Reyna, V., & Farley, F. (2006). Risk and rationality in adolescent decision-making: Implications for theory, practice, and public policy. *Psychological Science in the Public Interest*, *7*, 1–44.

Spear, P. (2000). The adolescent brain and age-related behavioral manifestations. *Neuroscience and Biobehavioral Reviews*, *24*, 417–463.

Steinberg, L. (2004). Risk-taking in adolescence: What changes, and why? *Annals of the New York Academy of Sciences*, *1021*, 51–58.

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.

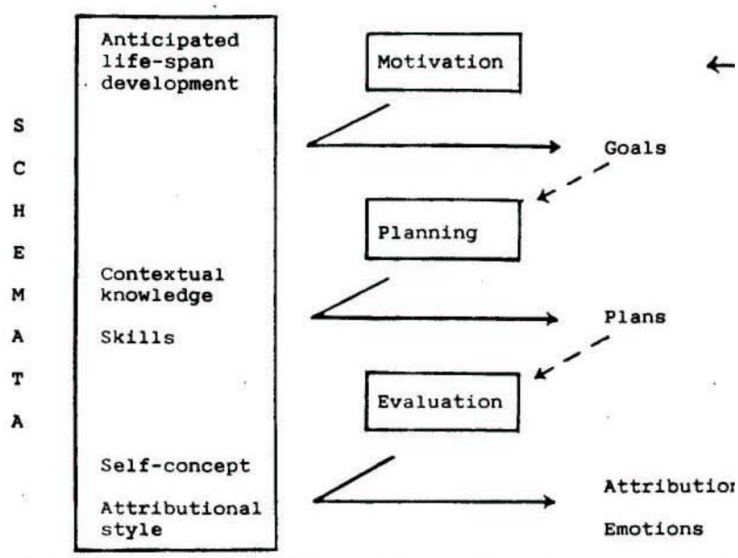

FIG. 1. *Orientation to the future in terms of the three processes invc*

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.

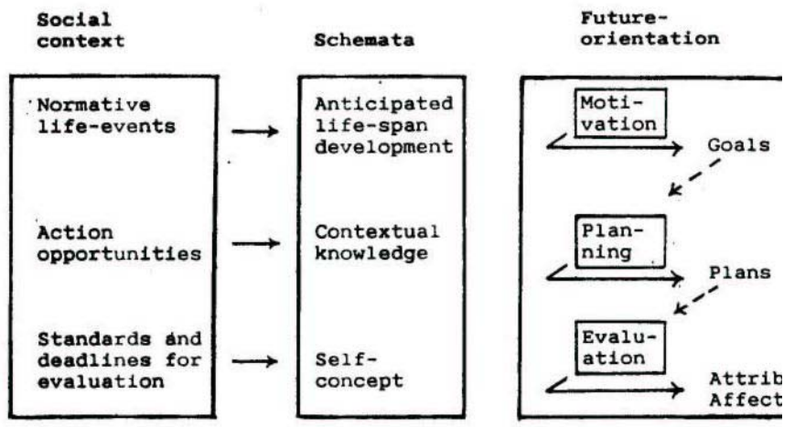

FIG. 2. *A contextual approach to adolescents' orientation to the futur*

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.
Pulkkinen (1984)	154 Finnish	20 Longitudinal study (8–20)	Interview	Sex, family, atmosphere	Content, planning, realism	Females had shorter extension than males. 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 48 Americans, 149 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. 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.

REFERENCES

Agarwal, A., & Tripathi, K. K. (1980). Time perspective in achievement motivation. Psychologia: An International Journal of Psychology in the Orient, 23, 50--62.

Agarwal, A., Tripathi, K. K., & Srivastava, M. (1983). Social roots and psychological implications of time perspective. International Journal of Psychology, 18, 367-380. Ainsworth, M. D. S. (1979). Infant-mother attachment. American Psychologist, 34, 932-937.

Bandura, A. (1986). Social foundation of thought and action. Englewood Cliffs, N J: Prentice-Hall. Barton, E. (1985). Threat of war in the minds of children. Lancet, 8422, 226.

Bell, D. C., & Bell, L. G. (1983). Parental validation and support in the development of adolescent daughters. In H. D. Grotevant & C. R. Cooper (Eds.), Adolescent development in the family. San Francisco: Jossey-Bass.

Bengtson, V. L., & Black, K. D. (1973). Intergenerational relations and continuities in socialization. In P. B. Baltes & K. W. Schaie (Eds.), Life-span developmental psychology, personality, and socialization. New York: Academic Press.

Bentley, A. M. (1983). Personal and global futurity in Scottish and Swazi students. Journal of Social Psychology, 12, 223-229.

Black, W. A., & Gregson, R. A. (1973). Time perspective, purpose in life, extraversion and neuroticism in New Zealand prisoners. British Journal of Social and Clinical Psychology, 12, 50--60.

Blasi, A., & Hoeffel, E. C. (1974). Adolescence and formal operations. Human Development, 17, 3A.A. 363.

Boocock, S. S. (1978). Getting started adult life: Crucial turning points for adult people. In J. C. Flanagan (Ed.), Perspectives on improving education--Project Talent's young adults look back. New York: Praeger.

Bosma, H. A. (1985). Identity development in adolescence. Coping with commitments. Groningen: Rijksuniversiteit Te Groningen.

Brandtstadter, J. (1984). Personal and social control over development: Some implications of an action perspective in life-span psychology. In P. B. Baltes & O. G. Brim (Eds.), Life-span development and behaviour (Vol. 6). New York: Academic Press. Cameron, P., Desai, K. G., Bahador, D., & Dremel, G. (1977-78). Temporality across the

life-span. International Journal of Aging and Human Development, 8, 22%259. Cantor, N., & Kihlstrom, J. F. (1987). Personality and social intelligence. Englewood Cliffs, N J: Prentice-Hall.

Cantor N., Norem, J., Niedenthal, P., Langston, C., & Brower, A. (1987). Life-tasks, self-concept ideals and cognitive strategies in a life transition. Journal of Personality and Social Psychology, 53, 1178--1191.

Cartron-Guerin, A., & Levy, P. (1980). [Achievement and future time perspective among preadolescents: Range, nature, and optimism of future plans. (French)]. Bulletin de Psychologie, 33,747-753. [English Abstract in Psychological Abstracts, 1982, 67, 1020.]

Chivian, E., Mack, J. E., Waletzky, J. P., Lazaroff, C., Doctor, R., & Goldenring, J. M. (1985). Soviet children and the threat of nuclear war: A preliminary study. American Journal of Orthopsychiatry, 55, 484--502.

Conger, J. J. (1973). Adolescence and youth: Psychological development in a changing world. New York: Harper & Row.

Cooper, C. R., Grotevant, H. D., & Condom S. M. (1983). Individuality and connectedness in the family as a context for adolescent identity formation and role-taking skill. In H. D. Grotevant & C. R. Cooper (Eds.), Adolescent development in the family. San Francisco: Jossey-Bass.

Coopersmith, S., Regan, M., & Dick, L. (1975). The myth of generation gap. San Francisco: Albion.

Cottle, T. J., & Klineberg, S. L. (1974). The present of things future. New York: MacMillan.

Dannefer, D. (1984). Adult development and social theory: A paradigmatic reappraisal. American Sociological Review, 49, 100--116.

Dittmann-Kohli, F. (1986). Problem identification and definition as important aspects of adolescents' coping with normative life-tasks. In R. K. Silbereisen, K. Eyferth, & G. Rudinger (Eds.), Development as action in context. Problem behavior and normal youth development. Berlin: Springer-Verlag.

Dreher, E., & Oerter, R. (1986). Children's and adolescents' conceptions of adulthood: The changing view of a crucial developmental task. In R. K. Silbereisen, K. Eyferth, & G. Rudinger (Eds.), Development as action in context. Problem behavior and normal youth development. Berlin: Springer-Verlag.

Dreher, M., & Oerter, R. (1987). Action planning competencies during adolescence and early adulthood. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press. Elkind, D. (1967). Egocentrism in adolescence. Child Development, 38, 1025-1034.

Elkind, D. (1980). Strategic interactions in early adolescence. In J. Adelson (Ed.), Handbook of adolescent psychology. New York: John Wiley & Sons.

Emmons, R. A. (1986). Personal strivings: An approach to personality and subjective well-being. Journal of Personality and Social Psychology, 51, 1058-1068.

Freire, E., Gorman, B., & Wessman, A. E. (1980). Temporal span, delay of gratification, and children's socioeconomic status. Journal of Genetic Psychology, 137, 247-255.

Friedman, S. H., Kofsky Scholnick, E., & Cocking, R. R. (1987). Reflections on reflections: what planning is and how it develops. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press.

Gilchrist, L. D., & Schinke, S. P. (1987). Adolescent pregnancy and marriage. In V. B. Van Hasselt & M. Hersen (Eds.), Handbook of adolescent psychology. New York: Pergamon Press.

Gillies, P., Elmwood, J. M., & Hawtin, P. (1985). Anxieties in adolescents about employment and war. British Medical Journal, 291, 383.

Gillispie, J. M., & Allport, G. W. (1955). Youth's outlook on the future (a cross-national study). New York: Doubleday & Company.

Gjesme, T. (1981). Is there any future in achievement motivation? Motivation and Emotion, 5, 115-138.

Goldberg, S., LaCombe, S., Levinson, D., Ross Parker, K. R., Ross, C., & Sommers, F. (1985). Thinking about the threat of nuclear war: Relevance to mental health. American Journal of Orthopsychiatry, 55, 503--512.

Goldenring, J. M., & Doctor, R. M. (1984). California adolescents' concerns about the threat of nuclear war. In T. Solantaus, E. Chivian, M. Vartanyan, & S. Chivian (Eds.), Impact of the threat of war on children and adolescents. (Proceedings of an international symposium, Helsinki, Finland, 1984). Boston: International Physician for the Prevention of Nuclear War.

Greene, A. L. (1986). Future-time perspective in adolescence: The present of things future revised. Journal of Youth and Adolescence, 15, 99-111.

Grotevant, H. D., & Cooper, C. R. (1986). Individuation in family relationships. A perspective on individual differences in the development of identity and role-taking skill in adolescence. Human Development, 29, 82-100.

Hacker, W. (1985). Activity: A fruitful concept in industrial psychology. In M. Frese & J. Sabini (Eds.), Goal-directed behavior: the concept of action in psychology. Hillsdale, N J: Lawrence Erlbaum Association.

Harren, V. A. (1979). A model of career decision making for college students. Journal of Vocational Behavior, 14, 119-133.

Havighurst, R. J. (1948/1974). Developmental tasks and education (3rd ed.). New York: McKay. (Original work published in 1948.)

Heckel, R. V., & Rajagopal, J. (1975). Future time perspective in Indian and American college students. Journal of Social Psychology, 95, 131-132.

Heckhausen, J. (1987). Balancing for weaknesses and challenging developmental potential: A longitudinal study of mother-infant dyads in apprenticeship interaction. Developmental Psychology, 23, 762-770.

Heppner, P. P. (1978). A review of the problem-solving literature and its relationship to the counseling process. Journal of Counseling Psychology, 25, 366-375.

Hoornaert, J. (1973). Time perspective: Theoretical and methodological considerations. Psychologica Belgica, xiii-3, 265-294.

Jones, E. E., & Berglas, S. (1978). Control of attributions about the self through self-handicapping: The appeal of alcohol and the rate of underachievement. Personality and Social Psychology Bulletin, 4, 200-206.

Jurkovic, G. J., & Ulrici, D. (1985). Empirical perspectives on adolescents and their families. In L. L'Abate (Ed.), The handbook of family psychology and therapy. Chicago: The Dorsey Press.

Kandel, D. B., & Lesser, G. S. (1969). Parental and peer influence on educational plans of adolescents. American Sociological Review, 34, 213-223.

Keating, D. P. (1980). Thinking processes in adolescence. In J. Adelson (Ed.), Handbook of adolescent psychology. New York: John Wiley & Sons.

Klineberg, S. L. (1967). Changes in outlook of the future between childhood and adolescence. Journal of Personality and Social Psychology, 7, 185-193.

Kreitler, S., & Kreitler, H. (1987). Plans and planning: Their motivational and cognitive antecedents. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press.

Kuo, S., &Spees, E. R. (1983). Chinese-American student life-style: A comparative study. Journal of College Student Personnel, 24, 111-117.

Lamm, H., Schmidt, R. W., & Trommsdorff, G. (1976). Sex and social class as determinants of future orientation in adolescent. Journal of Personality and Social Psychology, 34, 317-326.

Landau, S. F. (1969). The effect of length of imprisonment and subjective distance from release on future time perspective and time estimation of prisoners. Scripta Hierosolymitana, 21. Studies in Criminology. Jerusalem: Magness Press.

Landau, S. F. (1976). Delinquency, institutionalization, and time orientation. Journal of Consulting and Clinical Psychology, 44, 745-759.

Lazarus, R., & Folkman, S. (1987). Transactional theory and research on emotions and coping. European Journal of Personality, 1, 141-169:

Leontiev, A. N. (1979). Tiitigkeit, Bewusstsein, Pers6nlichkeit (Action, cognition, and personality). Stuttgart: Klett-Cotta.

Lessing, E. E. (1972). Extension of personal future time perspective, age, and life satisfaction of children and adolescents. Developmental Psychology, 6, 457--468.

Levine, M., Spivack, G., FuschiUo, J., & Tavernier, A. (1959). Intelligence and measures of inhibition and time sense. Journal of Clinical Psychology, 15, 224--226.

Lueptow, L. B. (1984). Adolescent sex roles and social change. New York: Columbia University Press.

Marcia, J. E. (1980). Identity in adolescence. In J. Adelson (Ed.), Handbook of adolescent psychology. New York: John Wiley & Sons.

Markus, H., & Wurf, E. (1987). The dynamic self-concept: A social psychological perspective. Annual Review of Psychology, 38, 299-337.

Marsh, H. W., Cairs, L., Relich, J., Barnes, J., & Debus, R. (1984). The relationship between dimensions of self-attribution and dimensions of self-concept. Journal of Educational Psychology, 76, 3-32.

Matas, L., Arend, R. A., & Sroufe, L. A. (1978). Continuity of adaptation in the second year: the relationship between quality of attachment and later competence. Child Development, 49, 547-556.

McGillicuddy-De Lisi, A. V., Flaugher, J., & Sigel, I. E. (1987). Familial influences on planning. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press.

Meade, R. D. (1968). Psychological time in India and America. Journal of Social Psychology, 76, 169-174.

Meade, R. D. (1971). Future time perspectives of college students in America and India. Journal of Social Psychology, 83, 175-182.

Meade, R. D. (1972). Future time perspectives of Americans and sub-cultures in India. Journal of Cross-Cultural Psychology, 3, 93-99.

Mehta, P. H., Rohila, P. K., Sundberg, N. D., & Tyler, L. E. (1972). Future time perspective of adolescents in India and the United States. Journal of Cross-Cultural Psychology, 3, 293-302.

Meissner, W. W. (1961). Some indications of sources of anxiety in adolescents. Journal of Genetic Psychology, 99, 65-73.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). Plans and the structure of behavior. New York: Holt, Rinehart & Winston.

Mindick, B., Oskamp, S., & Berger, D. E. (1977). Prediction of success or failure in birth planning: An approach to prevention of individual and family stress. American Journal of Community Psychology, 5, 447--459.

Mfnks, F. (1968). Future time perspective in adolescents. Human Development, 11, 107-123.

Neimeyer, G. J., Nevill, D. D., Probert, B., & Fukuyama, M. (1985). Cognitive structures in vocational development. Journal of Vocational Behavior, 27, 191-201.

Neisser, U. (1976). Cognition and reality. Principles and implications of cognitive psychology. San Francisco: Freeman.

Newman, B. M., & Newman, P. R. (1975). Development through life. A psychosocial approach. Homewood: The Dorsey Press.

Niemi, P. (1988). Adolescents and the family: Images and experiences of family life in Finland. Annales Universitatis Turkuensis, B, 181. Turku: University of Turku. Nunnally, J. C. (1978). Psychometric theory. New York: McGraw-Hill.

Nurmi, J.-E. (1987a, July). Adolescents' future orientation, life span, and socialization in the family context. A poster presented at the IX Biennial Meeting of International Society for the Study of Behavioral Development, Tokyo. (ERIC Document Reproduction Service No. ED 289 615)

Nurmi, J.-E. (1987b). Age, sex, social class, and quality of family interaction as determinants of adolescents' future orientation: A developmental task interpretation. Adolescence, 22, 977-991.

Nurmi, J.-E. (1988a). Experience of the threat of war among Finnish adolescents: Effects of thinking about the future, and comparison of methods. Medicine and War, 4, 199-210.

Nurmi, J.-E. (1988b, June). Parent-child interaction and adolescents' future orientation: The effects of age and sex. A poster presented at the Third European Conference on Development Psychology, Budapest. (ERIC Document Reproduction Service No. ED 297 849)

Nurmi, J.-E. (1989a). Adolescents' orientation to the future: Development of interests and plans, and related attributions and affects, in the life-span context. Commentationes

Scientiarum Socialium, 39. Helsinki: The Finnish Society for Sciences and Letters. Nurmi, J.-E. (1989b). Development of orientation to the future during early adolescence: A four-year longitudinal study and two cross-sectional comparisons. International Journal of Psychology, 24, 195-214.

Nurmi, J.-E. (1989c). Planning, motivation, and evaluation in orientation to the future: A latent structure analysis. Scandinavian Journal of Psychology, 30, 64-71.

Nurmi, J.-E. (1989d). The changing parent-child relationship, self-esteem, and intelligence as determinants of orientation to the future during early adolescence. (Department of Psychology, Research Report No. 10.) Helsinki: University of Helsinki.

Nurmi, J.-E. (1989e, July)Anticipated life-span development and orientation to the future among adolescents and adults. A paper presented at the X Biennial Meeting of International Society for the Study of Behavioral Development, Jyvaskyla.

Nuttin, J. R. (1974). A relational theory of motivation and the dynamic function of cognitive contents (Psychological Reports No. 4). Louvain: University of Louvain.

Nuttin, J. R. (1984). Motivation, planning, and action. A relational theory of behavior dynamics. Hillsdale, N J: Lawrence Erlbaum Associates.

Nuttin, J. R. (1985). Future time perspective and motivation. Leuven-Hillsdale: Leuven University Press-Erlbaum.

Oppenheimer, L. (1987). Cognitive and social variables in the plan of action. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press. Oppenheimer, L., & van der Wilk, R. (1987). Children's interests: Development and gender

differences. Unpublished manuscript, University of Amsterdam, Amsterdam. O'Rand, A., & Ellis, R. A. (1974). Social class and social time perspective. Social Forces, 53, 53--62.

Osipow, S. H. (1983). Theories of career development. Englewood Cliffs, N J: Prentice Hall. Payne, M. A. (1988). Adolescent fears: Some Caribbean findings. Journal of Youth and

Adolescence, 17, 255-266.

Pea, R. D., & Hawkins, J. (1987). Planning in a chore-scheduling task. In S. H. Friedman, E. Kofsky Scholnick, & R. R. Cocking (Eds.), Blueprints for thinking. The role of planning in cognitive development. Cambridge: Cambridge University Press.

Perlman, L. M. (1976). Temporal extension and orientation: A methodological study. Perceptual and Motor Skills, 43, 775-785.

Petersen, A. C. (1988). Adolescent development. Annual Review of Psychology, 39, 583--607.

Plante, J. A. (1977). A study of future time perspective and its relationship to the self-esteem and social responsibility of high school students. Dissertation Abstracts International, 38 (4-A), 1969--1970.

Poole, M. E., & Cooney, G. H. (1987). Orientations to the future: A comparison of adolescents in Australia and Singapore. Journal of Youth and Adolescence, 16, 129--151. Poole, M. E., Sundberg, N. D., & Tyler, L. E. (1982). Adolescents' perception of family

decision-making and autonomy in India, Australia, and the United States. Journal of Comparative Family Studies, 18, 349-357.

Position of Women. (1984). Statistical surveys, 72. Helsinki: The Statistical Office of Finland.

Powers, S. I., Hauser, S. T., Schwartz, J. M., Noam, G. G., & Jacobson, A. M. (1983). Adolescent ego development and family interaction: A structural-developmental perspective. In H. D. Grotevant & C. R. Cooper (Eds.), Adolescent development in the family. San Francisco: Jossey-Bass.

Pulkkinen, L. (1984, September). A longitudinal perspective on future-orientation in late adolescence. A paper presented at the XXIII International Congress of Psychology, Acapulco.

Rakowski, W. (1979). Future time perspective in later adulthood: Review and research directions. Experimental Aging Research, 5, 43--88.

Rappaport, H., Enrich, K., & Wilson, A. (1985). Relation between ego identity and temporal perspective. Journal of Personality and Social Psychology, 48, 1609-1620.

Rauste-von Wright, M. (1987). On the life process among Finnish adolescents. Summary report of a longitudinal study. Commentationes Scientiarium Socialium, 35. Helsinki: The Finnish Society of Sciences and Letters.

Ruiz, R. A., Reivich, R. S., & Krauss, H. H. (1967). Tests of temporal perspective: Do they measure the same construct? Psychological Reports, 21, 8A,A, 852.

Rychlak, J. F. (1973). Time orientation in positive and negative free phantasies of mildly abnormal versus normal high school males. Journal of Consulting and Clinical Psychology, 41, 175-180.

Seginer, R. (1983). Parents' educational expectations and children's academic achievements: A literature review. Merrill-Palmer Quarterly, 29, 1-23.

Seginer, R. (1988a). Adolescents facing the future. Cultural and sociopolitical perspectives. Youth and Society, 19, 314-333.

Seginer, R. (1988b). Social milieu and future-orientation: The case of kibbutz vs. urban adolescents. International Journal of Behavioral Development, 11,247-273. Siegman, A. W. (1961). The relationship between future time perspective, time estimation,

and impulse control in a group of young offenders and in a control group. Journal of Consulting Psychology, 25, 470--475.

Sigel, I. E. (1982). The relationship between parental distancing strategies and the child's cognitive behavior. In L. M. Laosa & I. E. Sigel (Eds.), Families as learning environments for children. New York: Plenum Press.

Solantaus, T. (1987). Hopes and worries of young people in three European countries.

Health Promotion, 2, 19-27.

Solantaus, T., Rimpel~i, M., & Rahkonen, O. (1985). Social epidemiology of experience of the threat of war among Finnish youth. Social Science and Medicine, 21, 145-151. Solantaus, T., Rimpel~i, M., & Taipale, V. (1984). The threat of war in the minds of 12- to 18-year-olds in Finland. Lancet, 8380, 784-785.

Sroufe, L. A. (1979). The coherence of individual development. American Psychologist, 34, 834--841.

Sundberg, N. D., Poole, M. E., & Tyler, L. E. (1983). Adolescents' expectations of future events--A cross-cultural study of Australians, Americans, and Indians. International Journal of Psychology, 18, 415--427.

Sundberg, N. D., Sharma, V., Rohila, P. K., & Wodtli, T. (1969). Family cohesiveness and autonomy of adolescents in India and the United States. Journal of Marriage and Family, 31, 403--40"].

Sundberg, N. D.,& Tyler, L. E. (1970). Awareness of action possibilities of Indian, Dutch, and American adolescents. Journal of Cross-Cultural Psychology, 1, 153-157. Tallman, I., Marotz-Baden, R., & Pindas, P. (1983). Adolescent socialization in Crosscultural perspective. Planning for social change. New York: Academic Press.

Taylor, S. M. (1985). The roles of occupational knowledge and vocational self-concept crystallization in students' school-to-work transition. Journal of Counseling Psychology, 32, 539-550.

Tinsley, H. E. A., & Heesacker, M. (1984). Vocational behavior and career development, 1983: A review. Journal of Vocational Behavior, 25, 139-190.

Trommsdorff, G. (1983). Future orientation and socialization. International Journal of Psychology, 18, 381-406.

Trommsdorff, G. (1986). Future orientation and its relevance for development as action. In R. K. Silbereisen, K. Eyferth, & G. Rudinger (Eds.), Development as action in context.

Problem behavior and normal youth development. Berlin: Springer-Verlag. Trommsdorff, G., Burger, C., & Fuchsle, T. (1982). Social and psychological aspects of future orientation. In M. Irle (Ed.), Studies in decision making. Berlin: de Gruyter. Trommsdorff, G., Burger, C., Fuchsle, T., & Lamm, H. (1978). Erziehungfur die Zukunft

(Education for the future). Dusseldorf: P/idagogischer Verlag Schwann.

Trommsdorff, G., & Lamm, H. (1975). An analysis of future orientation and some of its social determinants. In J. T. Fraser & H. Lawrence (Eds.), The study of time II. New York: Springer.

Trommsdorff, G., & Lamm, H. (1980). Future orientation of institutionalized and noninstitutionalized delinquents and nondelinquents. European Journal of Social Psychology, 10, 247-278.

Trommsdorff, G., Lamm, H., & Schmidt, R. W. (1979). A longitudinal study of adolescents'

future orientation (time perspective). Journal of Youth and Adolescence, 8, 132-147.

Tyszko-wa, M. (1980). Zur Entwicklung der VorsteUung der Jugend uber ihre Lebensperspektiven und deren Bedingheit (The development of adolescents' life perspectives and factors influencing them). In A. Kossakowski (Ed.), Psychologie im Sozialismus (Psychology in socialism). Berlin: VEB Deutscher Verlag der Wissenschaften. Verstraeten, D. (1980). Level of realism in adolescent future time perspective. Human Development, 23, 177-191.

Vincent, J. W. (1965). An investigation of constricted and extended temporal perspectives. Unpublished master thesis, University of Oregon.

de Voider, M. (1979). Time orientation: A review. Psychologica Belgica, XIX-1, 61-79.

Vygotsky, L. S. (1978). Mind in society. The development of higher psychological processes, J. Cole, V. John-Steiner, S. Schribner, & E. Souberman (Eds.). Cambridge, MA: Cambridge University Press.

Wallace, M., & Rabin, A. I. (1960). Temporal experience. Psychological Bulletin, 57, 213-236.

Waterman, A. S. (1982). Identity development from adolescence to adulthood: An extension of theory and a review of research. Developmental Psychology, 18, 341-358.

Webb, J., & Mayers, B. S. (1974). Developmental aspects of temporal orientation in adolescents. Journal of Clinical Psychology, 30, 504-507.

Weiner, B. (1985). An attributional theory of achievement motivation and emotion. Psychological Review, 92, 548-573.

White, K. M., Speisman, J. C.., & Cosios, D. (1983). Young adults and their parents: Individuation to mutuality. In H. D. Grotevant & C. R. Cooper (Eds.), Adolescent development in the family. San Francisco: Jossey-Bass.

Wilks, J. (1985). The relative importance of parents and friends in adolescent decision making. Journal of Youth and Adolescence, 15, 323-334.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. Journal of Child Psychology and Psychiatry, 17, 89--100.

Wood, D., & Middleton, D. (1975). A study of assisted problem-solving. British Journal of Psychology, 66, 181-191.

yon Wright, J. M., & Rauste-von Wright, M. (1977). Sex differences in personal and global future time perspective. Perceptual and Motor Skills, 44, 30.

ztinker, V. G. (1986). Career counseling: Applied concepts of life-planning. Monterey, CA: Brooks/Cole.

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Review

The maturation of incentive processing and cognitive control

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ABSTRACT

Understanding how immaturities in the reward system affect decision-making can inform us on adolescent vulnerabilities to risk-taking, which is a primary contributor to mortality and substance abuse in this age group. In this paper, we review the literature characterizing the neurodevelopment of reward and cognitive control and propose a model for adolescent reward processing. While the functional neuroanatomy of the mature reward system has been well-delineated, adolescent reward processing is just beginning to be understood. Results indicate that adolescents relative to adults demonstrate decreased anticipatory processing and assessment of risk, but an increased consummatory response. Such differences could result in suboptimal representations of reward valence and value and bias adolescent decision-making. These functional differences in reward processing occur in parallel with on-going structural and pharmacological maturation in the adolescent brain. In addition to limitations in incentive processing, basic cognitive control abilities, including working memory and inhibitory control, continue to mature during adolescence. Consequently, adolescents may be limited, relative to adults, in their abilities to inhibit impulsive behaviors and reliably hold 'on-line' comparisons of potential rewards/punishments during decision-making.

Contents

1. Introduction

Adolescence refers to the developmental time period between childhood and adulthood, generally considered to encompass ages 12–17 in humans, taking into account variability in factors such as puberty and gender (Spear, 2000; Dahl, 2004). In parallel with obvious pubertal changes (e.g., increases in height, weight, and secondary sex characteristics), a number of characteristic behaviors emerge during adolescence, including heightened sensation- and novelty-seeking and increased behavioral impulsivity (Arnett, 1992; Spear, 2000). These changes appear to be highly conserved behavioral traits, as they have been observed across cultures and even species (Spear, 2000;

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Laviola et al., 2003). On one hand, normative increases in these behaviors have been proposed to serve an adaptive function in that they promote exploration of the environment and the development of skills necessary for independence in adulthood (Kelley et al., 2004). On the other hand, such behaviors, particularly when coupled with immature cognitive control abilities, may increase the likelihood of engaging in risky and reckless behaviors, which can undermine survival (Zuckerman, 1979; Arnett, 1992; Spear, 2000; Zuckerman, 1994). Risk-taking is broadly defined here as engaging in behaviors that may be high in subjective desirability (i.e., associated with high sensation, novelty, or perceived reward) but exposes the individual to potential injury or loss. Examples of risk-taking include initiating use of addictive drugs, driving at excessive speeds, and engaging in unprotected sex (Arnett, 1992; Silveri et al., 2004; Dahl, 2004). Negative outcomes associated with adolescent risk taking are a major health concern for this age group (Spear, 2000; Dahl, 2004), resulting in dramatic increases in mortality rates despite peaks in other measurable aspects of physical health (Resnick et al., 1997; Call et al., 2002; Dahl, 2004).

A primary component of heightened sensation/novelty seeking and risk-taking in adolescence is immature brain circuitry mediating incentive (i.e., reward and punishment) processing (Arnett, 1992; Spear, 2000; Chambers et al., 2003; Ernst et al., 2006). Immaturities in incentive-related circuitry could, for example, lead to misevaluation of the value or predicted consequences associated with a given stimulus or action thereby biasing decision making. As an example, an adolescent with a still-maturing incentive processing system might decide that jumping his/her skateboard down a steep flight of stairs is highly rewarding, particularly if friends are watching, while not giving equal weight to the associated risk (e.g., the severe pain associated with a broken ankle) as might most adults. Characterization of the neurodevelopment of the reward system would promote understanding of adolescent risky behaviors and advance educational and intervention strategies for this age group (Dahl, 2004).

In addition to insight on risk-taking, our understanding of the etiology of mood and substance abuse disorders would be informed by the characterization of incentive processing during adolescence. Schizophrenia and depression, for instance, often emerge during the adolescent years (Sweeney et al., 2004; Everling and Fischer, 1998; Chau et al., 2004) and exhibit co-morbid abnormalities in incentive processing (Chau et al., 2004).

The normative maturation of incentive-related brain circuitry through adolescence is just beginning to be investigated in humans. Current data indicate that adolescents process incentives differently than adults, yet the nature, and more specifically the directionality of such differences remains uncertain (Chambers et al., 2003; Ernst et al., 2006; Spear, 2000) (see below). Furthermore, a mechanistic understanding of the interaction of adolescent incentive processing and other functional networks contributing to risk-taking is currently under-specified. That is, while immature incentive processing expectedly plays a primary role in these behaviors, additional functional brain systems including those mediating core aspects of cognitive control are critically intertwined and need to be jointly considered.

In this paper, we review the literature on the maturation of incentive processing and basic components of cognitive control as an initial step towards generating a clearer picture of adolescent behavior and vulnerabilities to risk-taking. We begin by highlighting two broad theoretical models that posit how adolescent incentive processing differs from adults. We then provide well-characterized evidence describing primary elements of the adult reward system followed by a review on what is currently known regarding the adolescent system. A description of brain maturation and cognitive development follows in order to provide an overall picture of the collective limitations that affect the motivation and decision-making systems during adolescence.

2. Models of adolescent incentive processing

Two models emerge from the adolescent reward literature which characterize how incentive processing is different in adolescents compared to adults, and how such processing may contribute to risk-taking (Spear, 2000; Chambers et al., 2003; Ernst et al., 2006). Both models agree that adolescents recruit a similar underlying brain circuitry and that there is a fundamental difference in the way that the adolescent brain processes incentives relative to adults. The models diverge, however, in terms of the directionality of this difference.

One model suggests that the adolescent incentive processing system is *hypo*-active relative to adults and results in reduced motivation (Spear, 2000). In other words, those brain areas that process incentives are not recruited as strongly or to the same degree as they are in adults given equivalent reward contingency. In this model, risk-taking is explained as adolescents seeking out experiences with high reward values because those with more modest value are not sufficiently appetitive or enticing enough to drive a normatively under-active reward system, specifically the ventral striatum (Spear, 2000). As a consequence, adolescents may be more vulnerable to drug addiction, for example, because they require quantitatively more drug per use to drive a hypo-responsive reward system. This model shares general similarity to accounts of adult dopamine (DA) hypo-function (Spear, 2000) and a model of ADHD (Castellanos and Tannock, 2002) (see below).

In contrast, a second model suggests that adolescents are *hyper*-responsive to incentives. That is, adolescents demonstrate a heightened sensitivity to rewards and over-activate incentive-related brain circuitry compared to adults given the same reward contingency (Chambers et al., 2003; Ernst et al., 2006). Chambers et al. (2003), for example, point out that normative maturational increases in monoaminergic (dopamine) neurotransmitter activity in the fronto-striatal 'motivational' system compared to relatively lower levels of inhibitory (e.g., serotoninergic) mechanisms contribute to increased reward sensitivity in adolescents (Chambers et al., 2003). In typical development, increased activity in motivational circuitry serves an important adaptive function in that it leads to adolescents engaging in novelty and sensation-seeking behaviors which may promote independent skills necessary for survival in adulthood (Kelley et al., 2004). However, this increased activity could also confer vulnerability in adolescents in the form of a heightened sensitivity to the dependency producing effects of addictive drugs.

Hyper-active incentive processing is also central to a recently proposed triadic model (Ernst et al., 2006). This model suggests that during adolescence a normative imbalance exists between a hyperactive reward-driven system (e.g., ventral striatum-mediated) and limited harm-avoidant (e.g., amygdala-mediated) and regulatory/executive control (e.g., prefrontal cortex-mediated) circuitries. Behaviorally, adolescents are more 'reward-driven' (i.e., respond more strongly to rewards than adults) due to the interactions between these systems. The triadic model shares similarities with the model suggested by Chambers et al. (2003) in that there is an imbalance in reward and inhibitory circuitries during adolescence and that increased sensitivity to rewarding stimuli is hypothesized, particularly in the ventral striatum. The triadic model is novel in terms of emphasizing the notion of functional interconnectivity among multiple related circuitries including executive control to explain risk-taking.

The hypo- and hyper-active reward system models lead to contrasting predictions of neural activation and behavior in adolescents. In the following sections, we examine how the adolescent reward system may demonstrate both over- and under-active responses to a reward. We begin with a brief overview of the mature system as this establishes a useful framework for studying adolescents.

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3. Adult incentive processing

Incentive processing in the mature brain is supported by a relatively well-delineated circuitry. Single-cell studies in non-human primates have demonstrated that incentives modulate neuronal activity in several regions, including (but not limited to) the dorsal and ventral striatum VS; including (nucleus accumbens, NAcc), midbrain (ventral tegmental area, substantia nigra pars compacta), amygdala, orbitofrontal cortex (OFC), medial and lateral prefrontal cortex, and posterior parietal cortex (Apicella et al., 1991; Hikosaka et al., 2006; Schultz, 2000; Roesch and Olson, 2003; Wise, 2002; Roesch and Olson, 2004). Neuroimaging studies in humans have identified similar regions in adults (Thut et al., 1997; O'Doherty, 2004; McClure et al., 2004; Delgado et al., 2000; Knutson et al., 2000; Breiter et al., 2001; Delgado et al., 2003; Elliott et al., 2003).

Importantly, the temporal resolution afforded by single-cell and event-related functional magnetic resonance imaging (fMRI) studies have lead to the observation that specific brain regions carry temporally distinct information or 'signals' related to rewards (Schultz et al., 2000; O'Doherty, 2004). Fig. 1 schematically represents a sample of these reward-related signals, brain regions identified as subserving them, and their temporal relation with respect to incentive delivery. In this model, incentive signals are broadly categorized as those occurring prior to or after incentive delivery. Distinguishable signals occurring prior to incentive delivery include reward detection, as well as estimation of the valence and anticipated value of a future incentive (O'Doherty et al., 2002; Knutson and Cooper, 2005). The term 'value' is inconsistently defined in the literature and often used interchangeably with 'expected value', the magnitude of a reward X probability of its attainment (Schultz, 2004). Here, value is conceptualized as a complex interaction between an incentive's magnitude (i.e., amount of reward available) (Leon and Shadlen, 1999; Roesch and Olson, 2004; Wallis and Miller, 2003; Delgado et al., 2003), probability of attainment (O'Doherty, 2004), the time between action and incentive delivery (Tsujimoto and Sawaguchi, 2005), an animal's state of satiety (Critchley and Rolls, 1996), and subjective preference (Tremblay and Schultz, 1999; Hassani et al., 2001). Signals occurring after incentive delivery include, for example, those related to the magnitude and valence of the received incentive (Delgado et al., 2003; Delgado et al., 2000; Rolls, 2000; O'Doherty et al., 2001), as well as those corresponding to whether or not the outcome matched up with predictions ('prediction error' signals) (Schultz, 2000; Schultz and Dickenson, 2000; Hare et al., 2008). Importantly, several brain regions including the OFC, VS, and medial prefrontal cortex are consistently engaged and support computations that underlie these multiple incentive signals. For example, the OFC has been implicated in executive assessment of rewards including representations of subjective preference (Hare et al., 2008; Kringelbach, 2005), while the ventral striatum (VS) contributes to anticipatory processing, including initial reward detection and prediction (Knutson and Cooper, 2005). Thus, characterizing how these regions develop, in particular, is central to understanding limitations in specific aspects of reward system function during adolescence.

The discernable signals and the temporal nature of reward processing observed in the mature system form a useful framework in which to consider data generated on the adolescent reward system, which is discussed next.

4. Adolescent incentive processing

In contrast to the extensive literatures exploring the neural basis of mature incentive processing in non-human primates and human adults, fewer studies have specifically focused on the development of this system through adolescence in humans (May et al., 2004; van Leijenhorst et al., 2006; Bjork et al., 2007; Bjork et al., 2004; Ernst et al., 2005; Eshel et al., 2007; Galvan et al., 2006). Collectively, studies indicate that adolescent incentive processing is supported by a similar neural circuitry as adults, including orbitofrontal cortex, basal ganglia (dorsal and ventral striatum, including nucleus accumbens), amygdala, and medial prefrontal cortex. However, as will be illustrated below, the manner in which these regions are recruited by adolescents differs during the course of incentive processing.

May et al. (2004) found that children and adolescents recruit ventral striatum and orbital frontal cortex (similar to non-human primate reports) during the anticipation of reward or loss in a gambling task. This study was the first to apply event-related functional neuroimaging methods to child and adolescent incentive processing, but did not have an adult comparison group allowing for developmental comparisons to be made in terms of the recruitment of these primary regions. Studies which have investigated developmental differences between adolescents and adults in incentive processing have focused on different temporal aspects of incentive processing, leading to disparate conclusions. For example, Bjork et al. (2004) compared blood oxygenation level dependent (BOLD) changes during an anticipatory period (i.e., before responding to receive incentive) in adolescents and adults using the monetary incentive delay (MID) task (Knutson et al., 2000), a rewarded reaction time task. Briefly, in this task subjects first saw one of several geometric shapes, each of which was uniquely associated with a different magnitude of reward (money) available at trial end. Subjects then fixated a white crosshair for a variable delay period (i.e., the 'anticipation' period) after which they had to quickly respond via button press when a white square was flashed on the screen. If subjects responded while the square was still visible, they earned the promised reward. While adolescents performed similarly to adults on this task (by design), adolescents exhibited significantly less activation in the right ventral striatum (nucleus accumbens, NAcc) and extended-amygdala while anticipating responding for a reward (versus a condition where no reward was

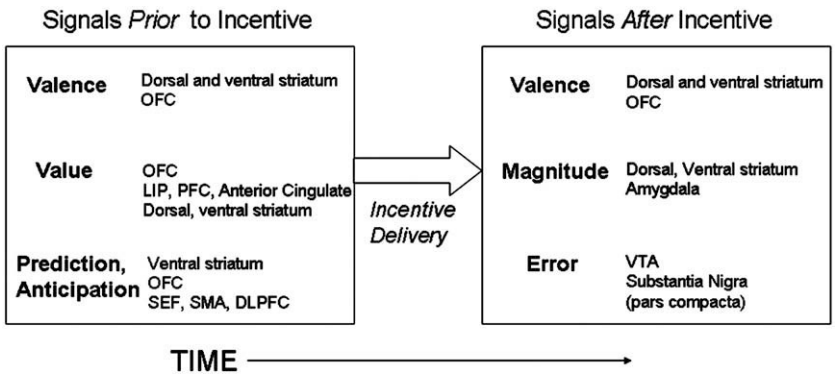

Fig. 1. Examples of dissociable incentive-related 'signals' and contributing brain regions. Incentive signals can be broadly categorized as those occurring prior to (e.g., reward detection, value; 'anticipatory processing') and after (e.g., prediction error signals; 'consummatory processing') incentive delivery (see text for references).

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available). Ernst et al. (2005) using fMRI examined changes in the BOLD response as subjects performed a rewarded decision-making task—the 'wheel of fortune' task. In this task, subjects had to choose via button press which half of a colored wheel they thought would be randomly picked by the computer (referred to as the 'choice' epoch). Each colored side was associated with a different magnitude of reward (win money) or punishment (lose money). Following a brief anticipation phase, subjects were presented with feedback about what color the computer selected (unbeknownst to the subjects, the color choice was selected at random but at a predetermined probability) and what incentive they received. During this feedback epoch (i.e., consummatory processing), adolescents demonstrated enhanced activity in the left nucleus accumbens, whereas adults exhibited more activity in the left amygdala, suggesting that adolescents are more sensitive to rewards (associated with NAcc) and adults are more sensitive to punishments (associated with amygdala) (Ernst et al., 2006). Subsequent work manipulated the probability of receiving a reward by changing the relative size of the colored wheel slices in the Wheel of Fortune task (Eshel et al., 2007). In this study, BOLD activity unique to the 'choice' epoch was investigated. Although behavioral performance did not differ across ages, adults activated OFC/VLPFC (BA 47, 10) and dorsal ACC (BA 32) significantly more than adolescents when making risky selections. These regions are known to contribute to aspects of cognitive control (Casey et al., 2001) as well as the monitoring and resolution of conflicting decisions (Carter et al., 1998). Results thus indicate that adolescents do not engage prefrontal regulatory mechanisms as much as adults when making risky choices. In a recent study, Bjork et al. (2007) investigated the circuitry supporting rewarded decision-making using a novel monetary game of 'chicken' in which subjects had to choose when to bank accumulating rewards before the trial unpredictably terminated. Trials varied in terms of the penalty associated with losing (failing to bank winnings before trial stopped). Adolescents activated posterior mesofrontal cortex, a region reported to be recruited during pre-response conflict and during the monitoring and avoidance of errors (Ridderinkhof et al., 2004), in a similar manner compared to adults in cases when a severe threat of loss was clear. However, under milder and more ambiguous conditions of risk, adolescents under-activated this region. Similarly, children (9 to 12 year-olds) compared to adults (18–26 year-olds) were found to recruit the anterior cingulate cortex more during high risk decision-making and engaged lateral orbitofrontal cortex more in response to negative compared to positive feedback (van Leijenhorst et al., 2006). These results suggest that younger subjects have limitations in reward assessment that may underlie their apparent under-activity of rewards when valence is harder to assess.

Galvan et al. (2006) using fMRI investigated BOLD differences in subjects performing a rewarded match-to-sample paradigm. Briefly, subjects saw one of three different visual cues (pictures of cartoon pirates) presented to the left or right of fixation, each of which was associated with a distinct reward value (different amounts of money). Following a brief delay, subjects saw two images of treasure chests to the left of right of fixation and were instructed to select (via button press and within 2 s) which chest appeared on the same side as the previous pirate picture. Subjects were then given feedback indicating if and how much they had won. Adolescents demonstrated an exaggerated response (higher magnitude of BOLD response) in NAcc relative to children or adults during the reward receipt epoch for large rewards. Furthermore, the extent (number of significantly active voxels) of NAcc activity in adolescents looked more like adults than children, overall. In OFC, adolescents looked more like children in terms of both extent and magnitude of activation. Results from this study were interpreted as reflecting a protracted development of OFC relative to NAcc and suggest that adolescents have limitations in the executive assessment of rewards and an overactive reward system.

Collectively, the studies suggest that the predictions of the hypo- and hyper-active models may not be mutually exclusive. For instance, Bjork et al. (2004) found under-activity in ventral striatum during a period when adolescents *anticipated responding* for rewards. This is a temporally distinct phase of incentive processing than that explored by Ernst et al. (2005) and Galvan et al. (2006), studies which report adolescents had increased activity when *receiving* reward. Thus, an important factor contributing to the hypo- versus hyper-active distinction may be the temporal stage of incentive processing under scrutiny—that is, distinct phases of incentive processing result in different patterns of activations.

Interestingly, Bjork et al. (2004) did not observe significant differences in the ventral striatum between adolescents and adults performing the MID task during reward receipt, an epoch more directly comparable with Ernst et al. (2005). One factor that may underlie these contradictory results is a difference in the levels of cognitive load demanded by the different tasks. Bjork et al. (2004) used a simple reaction time task where subjects simply responded to the appearance of a target, while the paradigms used by Galvan et al. (2006) and Ernst et al. (2006) required that subjects assess different responses and invoke working memory for instructions and past performance. More cognitively demanding tasks have been shown to recruit additional brain areas and/or increased activity within a single area (Rubia et al., 2000) and may increase the likelihood of recruiting reward-related brain areas.

Finally, we note that conclusions based on comparison of BOLD responses across different age groups are a common concern. The challenge put forth by neuroscientists investigating the adult system is that it is not straightforward if BOLD activity changes in fMRI studies are due to actual differences in neuronal computations or an isolated artifact due to immaturities in the vasculature or gross head size differences. Counter to these arguments, however, we note that brain size is adult-like early childhood (see Brain Maturation during Adolescence, below) and that the feasibility of comparing BOLD responses across developmental age groups transformed into a common stereotaxic space has been well established (Brown et al., 2005; Kang et al., 2003; Wenger et el., 2004). An additional concern is that performance differences in the scanner may lead to different levels or patterns of BOLD activity. We agree that this may be an effect in some studies. However, pediatric imaging studies frequently employ simple tasks easily performed by children (Luna et al., 2004a; Galvan et al., 2006) minimizing performance differences. Furthermore, when performance is equated across age groups (Bjork et al., 2004; Schlaggar et al., 2002), age-related functional differences are still observed.

Below, we next address *why* adolescents may demonstrate these particular patterns of functional brain activity—that is, what underlying brain mechanisms support these types of responses? From adolescence to adulthood, important brain structural and physiological changes occur with significant effects on brain function. Differences in brain maturational state, including thinning gray matter (e.g., synaptic pruning), increases in white matter (e.g., myelination), and neurotransmitter system differences, likely contribute to the particular functional patterns observed in adolescents and adults and are examined below.

5. Brain maturation during adolescence

Overall size, weight, cortical folding, and regional functional specialization of the human brain is adult-like by early childhood (Armstrong et al., 1995; Caviness et al., 1996; Giedd et al., 1996a; Giedd et al., 1996b; Reiss et al., 1996). While basic aspects of brain development are in place early, key processes continue to refine the basic structure to fit the biological and external environments. Two such processes include synaptic pruning and increased myelination (Huttenlocher, 1990; Jernigan et al., 1991; Pfefferbaum et al., 1994; Giedd et al., 1999b), which are critical to the developmental progression of the functional integration of frontal regions with the

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rest of the brain (Thatcher et al., 1987; Luna and Sweeney, 2004b; Chugani, 1998). These processes enhance neuronal processing and support mature cognitive control of behavior (Luna et al., 2004a).

5.1. Age-related gray matter reductions

Recent structural imaging studies with large subject pools indicate continued, non-linear reductions in gray matter through adolescence in cortical areas (Gogtay et al., 2004; Toga et al., 2006; Paus et al., 1999; Sowell et al., 1999a; Giedd et al., 1999a), as well as the basal ganglia (Sowell et al., 1999b). Such reduction in gray matter is largely due to the loss of weak or unused synapses via synaptic pruning (though other maturational processes such as glial cell changes, dendritic arborization, and vascular changes also contribute to this decline) (Gogtay et al., 2004). Synaptic pruning promotes enhanced information processing capacity, speed, and overall efficiency and supports complex computations within regional circuitry.

Gogtay et al. (2004) demonstrated a progressive decline of gray matter density throughout neocortex with increasing age. Notably, higher-order 'association' cortical areas including orbitofrontal cortex, dorsolateral prefrontal cortex, and the lateral temporal lobes, show persistent decreases in gray matter volume through adolescence (Gogtay et al., 2004). Evidence from post-mortem histological studies confirms a protracted rate of regional gray matter reduction with age that differs by region (Huttenlocher, 1990). For example, the middle frontal gyrus in prefrontal cortex continues to mature into adolescence, as opposed to visual cortex, which stabilizes near adult levels during childhood (Huttenlocher, 1990).

The basal ganglia (including dorsal and ventral striatum) and prefrontal areas, notably the orbitofrontal and dorsolateral prefrontal cortex, demonstrate comparably late maturation (Sowell et al., 1999b; Gogtay et al., 2004; Giedd, 2004). This observation has important ramifications for incentive processing during adolescence. As mentioned above, these regions underlie multiple incentive-related signals in adults. Immaturities in these areas would thus be expected to result in a limited ability to efficiently and accurately form representations of key signals like incentive valence and value. Furthermore, immaturities in the OFC and dorsal and ventral striatum would be expected to affect an adolescent's ability to generate reliable predictions of incentive outcome and perhaps feedback-based learning computations.

5.2. Age-related white matter increases

Myelination enhances the efficiency of information processing by increasing the speed and fidelity of distal neuronal transmission, aiding the functional integration of widely distributed circuitry, critical for the emergence of complex cognitive behavior (Goldman-Rakic et al., 1992; Luna and Sweeney, 2004b). Myelination increases in a linear fashion throughout development and occurs in parallel to the non-linear gray matter reductions described above (Yakovlev and Lecours, 1967). Similar to findings regarding gray matter, myelination does not occur last in frontal regions but throughout the brain. Frontal, temporal and parietal association areas continue to myelinate through adolescence compared to earlier maturation in occipital regions. Recent studies using diffusion tensor imaging (DTI), which measures the integrity of white matter presumed to mostly reflect myelination, substantiate previous histological work and, collectively, indicate a continued increase in measures of frontal white matter anisotropy throughout childhood and into adulthood, evidence for continued white matter integrity (myelination) with age (Klingberg et al., 1999; Barnea-Goraly et al., 2005; Mukherjee and McKinstry, 2006; Huppi and Dubois, 2006).

As noted above, a distributed yet limited number of brain areas are consistently activated during incentive processing, including spatially distant regions like the orbitofrontal cortex, basal ganglia (dorsal and ventral striatum/nucleus accumbens), amygdala, and lateral prefrontal cortex. The inter-connectivity of these brain regions has been well characterized (Alexander et al., 1986; Middleton and Strick, 1994; Middleton and Strick, 2000; Middleton and Strick, 2002; Carmichael and Price, 1995; Haber et al., 1995; Haber et al., 2000; Groenewegen et al., 1997). Importantly, accumulating evidence in human and animal studies suggests that pathways within and between these regions are not yet fully myelinated during adolescence. For example, Klingberg et al. (1999) demonstrated with DTI that fiber tracts throughout frontal cortex continue to myelinate well into the second decade of life. In another study, Olesen et al. (2003) combined DTI (structural) and fMRI (functional) analyses in 8–18 year olds and demonstrated that enhanced integrity of connections between superior frontal sulcus, inferior parietal lobe, and caudate were found to correlate with BOLD response and visual-spatial working memory performance. The Olesen et al. study importantly links brain structure with function, supporting the notion that increased myelination of pathways contributes to improved working memory abilities (Luna et al., 2004a; Demetriou et al., 2002). Similarly, Liston et al. (2006) demonstrated that enhanced integrity of fronto-striatal tracts correlated with improved performance on a go/no go task and with age. The fronto-striatal tract is a crucial communication route for top-down cognitive control mechanisms like response inhibition as well as incentive processing. Converging evidence of continued myelination in the developing brain also comes from the animal literature. For example, amygdalo-cortical pathways in rat continue to myelinate through adolescence (Benes et al., 1994). The progressive maturation of amygdalo-cortical pathways could provide one plausible mechanism for increasingly more inhibitory control affecting reward processing with age.

A normatively under-myelinated brain would be expected to undermine adolescents' ability to have efficient and rapid access to incentive signals as well as limit how rapidly these signals may be integrated and used to inform decision-making and guide behavior. Further, given that the overall value of an incentive is complex and may emerge from different processes (e.g., magnitude, delay to receipt, etc.), and that evidence suggests that these components are coded by distributed brain areas, accurate value representations, in particular, may rest on efficient functional connectivity between regions aided by myelination. Importantly, under-myelination would also make top-down, prefrontal cortex mediated cognitive control mechanisms like response inhibition (Liston et al., 2006) inefficient (see below) and may confer vulnerability to impulsive behaviors.

In addition to brain structural changes, important changes occur in key neurotransmitter systems during adolescence. Evidence for ongoing changes in dopamine signaling during adolescence will be briefly considered next.

5.3. Maturation of dopamine signaling

Dopamine (DA), a key monoamine neurotransmitter modulating reward circuitry (Kirsch et al., 2006), has been associated with multiple aspects of reward processing, including the hedonic value associated with rewards, motivation, and the reinforcement of rewarded behavior (Wise, 2004). Dopamine cells primarily originate from the zona compacta of the substantia nigra and the ventral tegmental area (VTA) and are known to project to components of the basal ganglia (nigrostriatal system), the limbic system, including hippocampus, amygdala, and nucleus accumbens (mesolimbic system), as well as to widespread areas of the frontal lobe (mesocortical system). Converging evidence from human and animal models indicates that the mechanisms underlying dopamine neurotransmission in striatal and cortical systems continue to mature during adolescence in a number of ways (Spear, 2000; Andersen, 2003; Crews et al., 2007). For example, human nigrostriatal DA neurons show the highest tyrosine hydroxylase (the rate limiting enzyme in dopamine

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synthesis) activity in childhood, followed by an exponential decrease during the next first three decades of life (Segawa, 2000). In rat striatum, D1 and D2 receptors levels are greater during adolescence compared to adulthood (Seeman et al., 1987). In addition to changing receptor levels, activity levels appear to change as well, with D1 and D2 receptor binding in the rat striatum peaking during adolescence (post-natal day 40) at levels that are 30–40% greater than in adults (Seeman et al., 1987; Spear, 2000). The density of dopamine transporters, which function to remove DA from the synapse, has also been shown to peak during adolescence in the striatum (Meng et al., 1999). Furthermore, evidence indicates that during adolescence, there is relatively greater activity in dopamine systems than in inhibitory serotonin (5-HT) systems, potentially resulting in an imbalance in reward (DA-mediated) and suppression (5-HT-mediated) mechanisms (Takeuchi et al., 2000; Lambe et al., 2000; Ernst et al., 2006; Spear, 2000). In mesocortical pathways, non-human primate work has shown that DA inputs to prefrontal cortex (PFC) peak in adolescence (Rosenberg and Lewis, 1994; Rosenberg and Lewis, 1995; Spear, 2000). In rats, DA fiber density to PFC also increases in adolescents relative to adults (Kalsbeek et al., 1988).

Developmental changes in dopamine signaling may provide insight on the functional differences observed between adolescent and adult incentive processing. First, as noted above there is a peak in the number of dopamine transporters in adolescence, which function to remove DA from the synapse. An increase in the number of transporters could lead to limitations in the ability to maintain motivation over a delay or anticipation period compared to adults. Indeed, a recent model of attention deficit hyperactivity disorder (ADHD) suggests that the premature removal of synaptic DA may lead to impairment in the ability to sustain motivation for a delayed reward (Castellanos and Tannock, 2002). As a behavioral consequence, short-term rewards may be favored over long-term rewards in individuals with ADHD (Krain and Castellanos, 2006). A peak in DAT resulting in normative limitations sustaining motivation across an anticipatory delay may explain adolescents' decreased activity in the nucleus accumbens as indicated in Bjork et al. (2004). Second, as demonstrated by Segawa (2000), nigrostriatal DA neurons and components of the basal ganglia show higher activity during adolescence than adulthood. Increased dopaminergic activity, coupled with thicker gray matter (and perhaps more synapses) in adolescents than in adults (Sowell et al., 1999b), may partially explain adolescents' enhanced response in the nucleus accumbens to the receipt of a reward—particularly when there is no delay before receiving it (and thus the increased transporters are not a factor).

6. Maturation of cognitive control

In parallel with functional changes in reward processing and ongoing structural and neurotransmitter differences, aspects of cognitive control also show protracted development through adolescence. The maturation of these cognitive control processes, including working memory and voluntary response suppression, may play significant roles in how incentives guide behavior by regulating what incentive-related information is accessible during decision-making. The maturation of voluntary response suppression and working memory, and their proposed relations to incentive-related processing and behavior, are discussed below.

6.1. Maturation of voluntary response suppression

Voluntary response suppression (also referred to as response inhibition) refers to the ability to inhibit task irrelevant responses to prepotent or salient stimuli in favor of goal-appropriate action. Inhibitory control is engaged when deciding among competing alternatives during decision making (Hooper et al., 2004; Pierrot-Deseilligny et al., 2003). As such, this system expectedly serves an important regulatory role in incentive-based decision-making. An immature voluntary response suppression system may bias an adolescent to respond to an immediate reward, even if that means neglecting a larger reward that is delivered later (i.e., delay discounting) (Yarkoni et al., 2005; Hariri et al., 2006).

A distributed neural circuitry underlies voluntary response suppression in adults, including dorsolateral prefrontal cortex (DLPFC), the cortical eye fields, anterior cingulate cortex, basal ganglia, superior colliculus, and thalamus, among others, as indicated by non-human primate electrophysiology (Munoz and Everling, 2004; Funahashi et al., 1993) and functional imaging work in human (Brown et al., 2006; Luna et al., 2001; Connolly et al., 2002; Ford et al., 2005).

Converging evidence from several studies demonstrates that inhibitory control of behavior continues to improve throughout childhood and well into adolescence. Compared to children, adolescents exhibit improved inhibitory performance during the Go-No-Go, Stroop, Flanker, and Stop signal tasks, and are able to more reliably hold fixation in the presence of visual distractors (Levin et al., 1991; Williams et al., 1999; Liston et al., 2006; Ridderinkhof et al., 1999; Paus et al., 1990; Luciana and Nelson, 1998; Tipper et al., 1989; Ridderinkhof et al., 1997). Work from our laboratory and others using the antisaccade task (Hallett, 1978), which measures the ability to halt an impending saccade to a suddenly appearing stimulus, indicates continued improvements in response suppression during adolescence, with adult-like levels of control stabilizing by mid-adolescence (Fischer et al., 1997; Fukushima et al., 2000; Klein and Foerster, 2001; Luna et al., 2004a; Munoz et al., 1998).

Although adolescents may appear to behave like adults on this task, they engage a different neural circuitry to do so. Our previous developmental antisaccade fMRI study indicated that performance on the antisaccade task is supported by the establishment of a widely distributed neural circuitry that shows continued refinement through adolescence (Luna et al., 2001; Luna et al., 2004a). Adolescents rely more heavily on less mature regions like the dorsolateral prefrontal cortex (DLPFC) while showing reduced involvement in inhibitory control areas like the cortical eye fields (FEF, SEF) (Luna et al., 2001) These data support other studies consistently indicating protracted development of inhibitory control circuitry (Rubia et al., 2000; Durston et al., 2006; Casey et al., 1997; Rubia et al., 2006; Rubia et al., 2007; Bunge et al., 2002; Adleman et al., 2002; Tamm et al., 2002; Marsh et al., 2006; Luna et al., 2001).

6.2. Maturation of working memory

Working memory refers to the ability to maintain and, when necessary, manipulate information on-line (Baddeley, 1983; Baddeley, 1992; Fuster, 1997). Working memory improvement throughout adolescence is important for the emergence of adult-level higher-order cognition (Nelson et al., 2000; Bjorklund and Harnishfeger, 1990); (Dempster, 1981; Dempster, 1981; Case, 1992). Immaturities in working memory would be predicted to limit adolescents' ability to maintain critical incentive related information (i.e., estimated reward value, probability of reward receipt, previous reward history, etc.), particularly when there are multiple and/or competing incentive stimuli, during decision-making.

Widely distributed brain areas are known to underlie working memory. In non-human primates, such areas include prefrontal cortex (Funahashi et al., 1997; Funahashi et al., 1993), frontal eye field (FEF) (Funahashi et al., 1989), supplementary eye field (SEF) (Hanes et al., 1995), inferior parietal lobule (Colby et al., 1996; Gnadt and Andersen, 1988), caudate nucleus (Hikosaka et al., 1989), and substantia nigra pars reticulata (SNpr) (Hikosaka and Wurtz, 1983). Functional imaging studies with humans implicate the dorsolateral prefrontal cortex (DLPFC), FEF, SEF, inferior parietal sulcus (IPS), cingulate cortex, basal ganglia, and lateral cerebellum (Brown et al., 2004; Cabeza and

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Nyberg, 2000; Petit et al., 1998; Curtis et al., 2004; LaBar et al., 1999; Passingham and Sakai, 2004; Postle et al., 2000; Geier et al., 2007; Postle et al., 2000; Sweeney et al., 1996; Wager and Smith, 2003).

Similar to voluntary response suppression, evidence suggests a prolonged development of working memory into adolescence (Swanson, 1999; Olesen et al., 2003; Luna et al., 2004a; Luciana and Nelson, 1998; Demetriou et al., 2002). Performance on spatial working memory tasks, for example, where subjects must remember the location of a briefly appearing target in space, continues to improve from childhood through adolescence (Zald and Iacono, 1998; Geier et al., 2009; Luna et al., 2004a; Scherf et al., 2006). Improvements in controlling interference may also contribute to increased efficiency of working memory in development (Bjorklund and Harnishfeger, 1990; Sakai et al., 2002). Although adolescents recruit a more specialized network of brain regions than children during spatial working memory tasks, they are not yet at adult levels of specificity (Scherf et al., 2006; Geier et al., 2009). Further, adolescents appear to necessitate more prefrontal activity (specifically right DLPFC) to achieve similar levels of behavioral performance (Scherf et al., 2006; Luna et al., 2008).

7. Incentive processing and cognitive control

Immature incentive processing is likely not the exclusive determinant of adolescent decision making leading to risk-taking. Rather, other functional circuitries including those mediating cognitive control are critically involved (Steinberg, 2004; Ernst et al., 2006). We propose a framework for advancing current understanding of adolescent incentive processing and risk-taking which emphasizes that incentive-related signals and core aspects of cognitive control, specifically response inhibition/inhibitory control and working memory, function together during decision-making. In this model, risk-taking behavior reflects the outcome of one or more suboptimal decisions (Ernst et al., 2006; Eshel et al., 2007). Contributing to suboptimal decision-making is the interaction of immature reward processing and inconsistencies/limitations in the cognitive control of behavior. Returning to a previous example, consider again the adolescent deciding whether or not to jump his skateboard down the stairs. Immature processing in regions like the orbitofrontal cortex, for example, may lead to an enhanced value estimation of landing the jump relative to sustaining an injury, and thus bias the adolescent to engage in the behavior. Fig. 2 schematically depicts a proposed relationship between incentive processing, cognitive control abilities, and behavioral outcome.

Numerous factors including cognitive, emotional, and social processes influence decision making and risk taking behavior (e.g., computational capacity, abstract thinking abilities, social context, time estimation, etc.). Our model focuses specifically on the influence of limited incentive processing in adolescence in the context of a still developing cognitive control system. While these elements are not the only ones at play in adolescent risk taking, delineating their limitations can help us begin to understand the platform where risk taking can emerge and where other factors can then also play a role. We propose that the increased yet short lived DA processing as well as immaturities in the local circuitries and connectivity of reward related regions result in an overactive system that is biased towards short term goals. These factors can then undermine a still immature cognitive control system that can either be enhanced by the added activation of the incentive processing or distracted from considering alternatives which could result in risk taking behavior. An increased incentive system can enhance areas that support the behavior that is related to receiving the reward which can result in adaptive behavior if the decision at hand is appropriate (performing an innocuous choice in a scientific experiment) or maladaptive behavior if the reward contingent behavior has immediate rewards (social approval from doing a risky skateboarding trick).

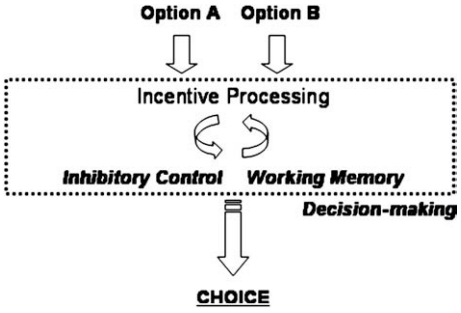

Fig. 2. A simple model emphasizing the interaction between incentive processing and basic cognitive control abilities in decision-making. Suboptimal decision-making has been suggested to contribute to risk-taking behavior. Immaturities in brain systems supporting how incentives are represented in the brain as well as in specific cognitive control systems like working memory and inhibitory control are proposed to underlie poor decision-making.

One assumption of the proposed model is that incentives should affect performance on tasks designed to probe working memory and inhibitory control. Indeed, recent work has shown incentive-related modulation of performance in working memory (Krawczyk et al., 2007) and response suppression (Duka and Lupp, 1997; Jazbec et al., 2006; Blaukopf and DiGirolamo, 2006) in adults, and, importantly, that there are developmental differences in how rewards affect basic aspects of cognitive control (Jazbec et al., 2006). Using a rewarded antisaccade task, Jazbec and colleagues have shown that adolescents demonstrate shorter antisaccade latencies and higher peak velocities on rewarded trials compared adults, who did not modulate saccadic parameters in this task based on reward contingency. These results suggest a fundamental difference in sensitivity to the effects of incentives on inhibitory behavior in adolescents compared to adults. Importantly, this work also highlights the notion that the relationship between incentives and cognitive control processes like response suppression may be bidirectional and complex. That is, on one hand, what incentive information decision-making brain regions use may be regulated by cognitive control mechanisms. On the other hand, incentives may also enhance aspects of cognitive control (e.g., inhibitory control). One possible explanation for this enhancement may be the dopamine system biasing collicular activity (Hikosaka et al., 2000).

8. Summary and conclusions

Adolescence is a transitional developmental period marked by normative increases in risk taking, which can oftentimes lead to maladaptive outcomes. In this paper, we reviewed the literature on brain systems supporting incentive processing and basic aspects of cognitive control including working memory and response inhibition as an initial step towards gaining insight on the neurobiological mechanisms underlying risk taking behavior. Current evidence indicates that adolescents relative to adults demonstrate under- or over-activity at different stages of reward processing such as early hypo-responsiveness in the executive assessment of rewards and later hyper-activity in consummatory responses. In parallel with these functional differences are on-going brain maturational processes like synaptic pruning and myelination, as well as regional changes in dopamine neurotransmission. A simple model of adolescent risk taking was presented which emphasized the need to consider the role of immature working memory and inhibitory control systems jointly with incentive processing during decision making. In sum, risk-taking behavior in adolescence may best be understood as an emergent property of a still-maturing brain still learning to integrate external and internal drives.

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References

Adleman NE, Menon V, Blasey CM, White CD, Warsofsky IS, Glover GH, et al. A developmental fMRI study of the Stroop Color-Word task. NeuroImage 2002;16: 61–75.

Alexander GE, DeLong MR, Strick PL. Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Annu Rev Neurosci 1986;9:357–81.

Andersen SL. Trajectories of brain development: point of vulnerability or window of opportunity? Neurosci Biobehav Rev 2003;27:3-18.

Apicella P, Ljungberg T, Scarnati E, Schultz W. Responses to reward in monkey dorsal and ventral striatum. Exp Brain Res 1991;85:491–500.

Armstrong E, Schleicher A, Omran H, Curtis M, Zilles K. The ontogeny of human gyrification. Cereb Cortex 1995;5:56–63.

Arnett J. Reckless behavior in adolescence: a developmental perspective. Dev Rev 1992;12: 339–73.

Baddeley A. Working memory. Science 1992;255:556–9.

Baddeley AD. Working memory. Philosophical Transactions of the Royal Society of London. Series B. Biol Sci 1983;B302:311–24.

Barnea-Goraly N, Menon V, Eckert M, Tamm L, Bammer R, Karchemskiy A, et al. White matter development during childhood and adolescence: a cross-sectional diffusion tensor imaging study. Cereb Cortex 2005;15:1848–54.

Benes FM, Turtle M, Khan Y, Farol P. Myelination of a key relay zone in the hippocampal formation occurs in the human brain during childhood, adolescence, and adulthood. Arch Gen Psychiatry 1994;51:477–84.

Bjork JM, Knutson B, Fong GW, Caggiano DM, Bennett SM, Hommer DW. Incentive-elicited brain activation in adolescents: similarities and differences from young adults. J Neurosci 2004;24:1793–802.

Bjork JM, Smith AR, Danube CL, Hommer DW. Developmental differences in posterior mesofrontal cortex recruitment by risky rewards. J Neurosci 2007;27:4839–49.

Bjorklund DF, Harnishfeger KK. The resources construct in cognitive development: diverse sources of evidence and a theory of inefficient inhibition. Dev Rev 1990;10:48–71.

Blaukopf CL, DiGirolamo GJ. Differential effects of reward and punishment on conscious and unconscious eye movements. Exp Brain Res 2006;174:786–92.

Breiter HC, Aharon I, Kahneman D, Dale A, Shizgal P. Functional imaging of neural responses to expectancy and experience of monetary gains and losses. Neuron 2001;30:619–39.

Brown JW, Bullock D, Grossberg S. How laminar frontal cortex and basal ganglia circuits interact to control planned and reactive saccades. Neural Networks: the official journal of the International Neural Network Society, vol. 17. 2004. p. 471–510.

Brown MR, Goltz HC, Vilis T, Ford KA, Everling S. Inhibition and generation of saccades: rapid event-related fMRI of prosaccades, antisaccades, and nogo trials. NeuroImage 2006;33:644–59.

Brown TT, Lugar HM, Coalson RS, Miezin FM, Petersen SE, Schlaggar BL. Developmental changes in human cerebral functional organization for word generation. Cereb Cortex 2005;15:275–90.

Bunge SA, Dudukovic NM, Thomason ME, Vaidya CJ, Gabrieli JD. Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. Neuron 2002;33: 301–11.

Cabeza R, Nyberg L. Imaging cognition II: an empirical review of 275 PET and fMRI studies. J Cogn Neurosci 2000;12:1-47.

Call KT, Reidel AA, Hein K, McLoyd V, Petersen A, Kipke M. Adolescent health and well-being in the twenty-first century: a global perspective. J Res Adolesc 2002;12:69–98.

Carmichael ST, Price JL. Limbic connections of the orbital and medial prefrontal cortex in macaque monkeys. J Comp Neurol 1995;363:615–41.

Carter CS, Braver TS, Barch DM, Botvinick MM, Noll D, Cohen JD. Anterior cingulate cortex, error detection, and the online monitoring of performance. Science 1998;280:747–9.

Case R. The role of the frontal lobes in the regulation of cognitive development. Brain Cogn 1992;20:51–73.

Casey BJ, Forman SD, Franzen P, Berkowitz A, Braver TS, Nystrom LE, et al. Sensitivity of prefrontal cortex to changes in target probability: a functional MRI study. Hum Brain Mapp 2001;13:26–33.

Casey BJ, Trainor RJ, Orendi JL, Schubert AB, ystrom LE, iedd JN, et al. A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. J Cogn Neurosci 1997;9:835–47.

Castellanos FX, Tannock R. Neuroscience of attention-deficit/hyperactivity disorder: the search for endophenotypes. Nat Rev Neurosci 2002;3:617–28.

Caviness VS, Kennedy DN, Bates JF, Makris N. The developing human brain: a morphometric profile. In: Thatcher RW, Reid Lyon G, Rumsey J, Krasnegor NA, editors. Developmental Neuroimaging: Mapping The Development of Brain and Behavior. New York: Academic Press; 1996. p. (pp. 3-14).

Chambers RA, Taylor JR, Petenza MN. Developmental neurocircuitry of motivation in adolescence: a critical period of addiction vulnerability. Am J Psychiatr 2003;160: 1041–52.

Chau DT, Roth RM, Green AI. The neural circuitry of reward and its relevance to psychiatric disorders. Curr Psychiatry Rep 2004;6:391–9.

Chugani HT. A critical period of brain development: studies of cerebral glucose utilization with PET. Prev Med 1998;27:184–8.

Colby CL, Duhamel JR, Goldberg ME. Visual, presaccadic, and cognitive activation of single neurons in monkey lateral intraparietal area. J Neurophysiol 1996;76:2841–52.

Connolly JD, Goodale MA, Menon RS, Munoz DP. Human fMRI evidence for the neural correlates of preparatory set. Nat Neurosci 2002;5:1345–52.

Crews F, He J, Hodge C. Adolescent cortical development: a critical period of vulnerability for addiction. Pharmacol Biochem Behav 2007;86:189–99.

Critchley HD, Rolls ET. Hunger and satiety modify the responses of olfactory and visual neurons in the primate orbitofrontal cortex. J Neurophysiol 1996;75:1673–86.

Curtis CE, Rao VY, D'Esposito M. Maintenance of spatial and motor codes during oculomotor delayed response tasks. J Neurosci 2004;24:3944–52.

Dahl RE. Adolescent brain development: a period of vulnerabilities and opportunities. Keynote address. Ann N Y Acad Sci 2004;1021:1-22.

Delgado MR, Locke HM, Stenger VA, Fiez JA. Dorsal striatum responses to reward and punishment: effects of valence and magnitude manipulations. Cogn Affect Behav Neurosci 2003;3:27–38.

Delgado MR, Nystrom LE, Fissell C, Noll DC, Fiez JA. Tracking the hemodynamic responses to reward and punishment in the striatum. J Neurophysiol 2000;84: 3072–7.

Demetriou A, Christou C, Spanoudis G, Platsidou M. The development of mental processing: efficiency, working memory, and thinking. Monogr Soc Res Child Dev 2002;67:1-155 [discussion 156].

Dempster FN. Memory span: sources of individual and developmental differences. Psychol Bull 1981;89:63-100.

Duka T, Lupp A. The effects of incentive on antisaccades: is a dopaminergic mechanism involved. Behav Pharmacol 1997;8:373–82.

Durston S, Davidson MC, Tottenham N, Galvan A, Spicer J, Fossella JA, et al. A shift from diffuse to focal cortical activity with development. Dev Sci 2006;9:1–8.

Elliott R, Newman JL, Longe OA, Deakin JF. Differential response patterns in the striatum and orbitofrontal cortex to financial reward in humans: a parametric functional magnetic resonance imaging study. J Neurosci 2003;23:303–7.

Ernst M, Nelson EE, Jazbec S, McClure EB, Monk CS, Leibenluft E, et al. Amygdala and nucleus accumbens in responses to receipt and omission of gains in adults and adolescents. NeuroImage 2005;25:1279–91.

Ernst M, Pine DS, Hardin M. Triadic model of the neurobiology of motivated behavior in adolescence. Psychol Med 2006;36:299–312.

Eshel N, Nelson EE, Blair RJ, Pine DS, Ernst M. Neural substrates of choice selection in adults and adolescents: development of the ventrolateral prefrontal and anterior cingulate cortices. Neuropsychologia 2007;45:1270–9.

Everling S, Fischer B. The antisaccade: a review of basic research and clinical studies. Neuropsychologia 1998;36:885–99.

Fischer B, Biscaldi M, Gezeck S. On the development of voluntary and reflexive components in human saccade generation. Brain Res 1997;754:285–97.

Ford KA, Goltz HC, Brown MR, Everling S. Neural processes associated with antisaccade task performance investigated with event-related FMRI. J Neurophysiol 2005;94: 429–40.

Fukushima J, Hatta T, Fukushima K. Development of voluntary control of saccadic eye movements. I. Age-related changes in normal children. Brain Develop 2000;22: 173–80.

Funahashi S, Bruce CJ, Goldman-Rakic PS. Mnemonic coding of visual space in the monkey's dorsolateral prefrontal cortex. J Neurophysiol 1989;61:331–49.

Funahashi S, Chafee MV, Goldman-Rakic PS. Prefrontal neuronal activity in rhesus monkeys performing a delayed anti-saccade task. Nature 1993;365:753–6.

Funahashi S, Inoue M, Kubota K. Delay-related activity in the primate prefrontal cortex during sequential reaching tasks with delay. Neurosci Res 1993;18:171–5.

Funahashi S, Inoue M, Kubota K. Delay-period activity in the primate prefrontal cortex encoding multiple spatial positions and their order of presentation. Behav Brain Res 1997;84:203–23.

Fuster JM. The prefrontal cortex. (3 ed.). New York: Raven Press; 1997.

Galvan A, Hare TA, Parra CE, Penn J, Voss H, Glover G, et al. Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. J Neurosci 2006;26:6885-2692.

Geier CF, Garver KE, Luna B. Circuitry underlying temporally extended spatial working memory. Neuoimage 2007;35:904–15.

Geier, C.F., Garver, K., Terwilliger, R., & Luna, B. The Development of Working Memory Maintenance. Journal of Neurophysiology 2009;101(1):84–99.

Giedd JN. Structural magnetic resonance imaging of the adolescent brain. Ann N Y Acad Sci 2004;1021:77–85.

Giedd JN, Blumenthal J, Jeffries NO, Castellanos FX, Liu H, Zijdenbos A, et al. Brain development during childhood and adolescence: a longitudinal MRI study. Nat Neurosci 1999a;2:861–3.

Giedd JN, Blumenthal J, Jeffries NO, Castellanos FX, Liu H, Zijdenbos A, et al. Brain development during childhood and adolescence: a longitudinal MRI study. Nat Neurosci 1999b;2:861–3.

Giedd JN, Snell JW, Lange N, Rajapakse JC, Casey BJ, Kozuch PL, et al. Quantitative magnetic resonance imaging of human brain development: ages 4–18. Cereb Cortex 1996a;6:551–60.

Giedd JN, Vaituzis AC, Hamburger SD, Lange N, Rajapakse JC, Kaysen D, et al. Quantitative MRI of the temporal lobe, amygdala, and hippocampus in normal human development: ages 4–18 years. J Comp Neurol 1996b;366:223–30.

Gnadt JW, Andersen RA. Memory related motor planning activity in posterior parietal cortex of macaque. Exp Brain Res 1988;70:216–20.

Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis AC, et al. Dynamic mapping of human cortical development during childhood through early adulthood. Proc Natl Acad Sci U S Am 2004;101:8174–9.

Goldman-Rakic PS, Bates JF, Chafee MV. The prefrontal cortex and internally generated motor acts. Curr Opin Neurobiol 1992;2:830–5.

Groenewegen HJ, Wright CI, Uylings HBM. The anatomical relationships of the prefrontal cortex with limbic structures and the basal ganglia. J Psychopharmacol 1997;11:99-106.

Haber SN, Fudge JL, McFarland NR. Striatonigrostriatal pathways in primates form an ascending spiral from the shell to the dorsolateral striatum. J Neurosci 2000;20: 2369–82.

Haber SN, Kunishio K, Mizobuchi M, Lynd-Balta E. The orbital and medial prefrontal circuit through the primate basal ganglia. J Neurosci 1995;15:4851–67.

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Hanes DP, Thompson KG, Schall JD. Relationship of presaccadic activity in frontal eye field and supplementary eye field to saccade initiation in macaque: Poisson spike train analysis. Exp Brain Res 1995;103:85–96.
Hare TA, O'Doherty J, Camerer CF, Schultz W, Rangel A. Dissociating the role of the orbitofrontal cortex and the striatum in the computation of goal values and prediction errors. J Neurosci 2008;28:5623–30.
Hariri AR, Brown SM, Williamson DE, Flory JD, de Wit H, Manuck SB. Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. J Neurosci 2006;26:13213–7.
Hassani OK, Cromwell HC, Schultz W. Influence of expectation of different rewards on behavior-related neuronal activity in the striatum. J Neurophysiol 2001;85:2477–89.
Hikosaka O, Wurtz RH. Visual and oculomotor functions of monkey substantia nigra pars reticulata. III. Memory-contingent visual and saccade responses. J Neurophysiol 1983;49:1268–84.
Hikosaka O, Nakumura K, Nakahara H. Basal ganglia orient eyes to reward. J Neurophysiol 2006;95:567–84.
Hikosaka O, Sakamoto M, Usui S. Functional properties of monkey caudate neurons. I. Activities related to saccadic eye movement. J Neurophysiol 1989;61:780–98.
Hikosaka O, Takikawa Y, Kawagoe R. Role of the basal ganglia in the control of purposive saccadic eye movements. Physiol Rev 2000;80:953–78.
Hooper CJ, Luciana M, Conklin HM, Yarger RS. Adolescents' performance on the Iowa Gambling Task: implications for the development of decision making and ventromedial prefrontal cortex. Dev Psychol 2004;40:1148–58.
Huppi PS, Dubois J. Diffusion tensor imaging of brain development. Semin Fetal Neonatal Med 2006;11:489–97.
Huttenlocher PR. Morphometric study of human cerebral cortex development. Neuropsychologia 1990;28:517–27.
Jazbec S, Hardin MG, Schroth E, McClure E, Pine DS, Ernst M. Age-related influence of contingencies on a saccade task. Exp Brain Res 2006;174:754–62.
Jernigan TL, Trauner DA, Hesselink JR, Tallal PA. Maturation of human cerebrum observed in vivo during adolescence. Brain 1991;114:2037–49.
Kalsbeek A, Voorn P, Buijs RM, Pool CW, Uylings HB. Development of the dopaminergic innervation in the prefrontal cortex of the rat. J Comp Neurol 1988;269:58–72.
Kang HC, Burgund ED, Lugar HM, Petersen SE, Schlagger BL. Comparison of functional activation foci in children and adults using a common stereotactic space. NeuroImage 2003;19:16–28.
Kelley AE, Schochet T, Landry CF. Risk taking and novelty seeking in adolescence: introduction to part I. Ann N Y Acad Sci 2004;1021:27–32.
Kirsch P, Reuter M, Mier D, Lonsdorf T, Stark R, Gallhofer B, et al. Imaging gene-substance interactions: the effect of the DRD2 TaqIA polymorphism and the dopamine agonist bromocriptine on the brain activation during the anticipation of reward. Neurosci Lett 2006;405:196–201.
Klein C, Foerster F. Development of prosaccade and antisaccade task performance in participants aged 6 to 26 years. Psychophysiology 2001;38:179–89.
Klingberg T, Vaidya CJ, Gabrieli JDE, Moseley ME, Hedehus M. Myelination and organization of the frontal white matter in children: a diffusion tensor MRI study. Neuroreport 1999;10:2817–21.
Knutson B, Cooper JC. Functional magnetic resonance imaging of reward prediction. Curr Opin Neurol 2005;18:411–7.
Knutson B, Westdorp A, Kaiser E, Hommer D. FMRI visualization of brain activity during a monetary incentive delay task. NeuroImage 2000;12:20–7.
Krain AL, Castellanos FX. Brain development and ADHD. Clin Psychol Rev 2006;26:433–44.
Krawczyk DC, Gazzaley A, D'Esposito M. Reward modulation of prefrontal and visual association cortex during an incentive working memory task. Brain Res 2007;1141:168–77.
Kringelbach ML. The human orbitofrontal cortex: linking reward to hedonic experience. Nat Rev Neurosci 2005;6:691–702.
LaBar KS, Gitelman DR, Parrish TB, Mesulam M. Neuroanatomic overlap of working memory and spatial attention networks: a functional MRI comparison within subjects. NeuroImage 1999;10:695–704.
Lambe EK, Krimer LS, Goldman-Rakic PS. Differential postnatal development of catecholamine and serotonin inputs to identified neurons in prefrontal cortex of rhesus monkey. J Neurosci 2000;20:8780–7.
Laviola G, Macri S, Morley-Fletcher S, Adriani W. Risk-taking behavior in adolescent mice: psychobiological determinants and early epigenetic influence. Neurosci Biobehav Rev 2003;27:19–31.
Leon MI, Shadlen MN. Effect of expected reward magnitude on the response of neurons in the dorsolateral prefrontal cortex of the macaque. Neuron 1999;24:415–25.
Levin HS, Culhane KA, Hartmann J, Evankovich K, Mattson AJ. Developmental changes in performance on tests of purported frontal lobe functioning. Dev Neuropsychol 1991;7:377–95.
Liston C, Watts R, Tottenham N, Davidson MC, Niogi S, Ulug AM, et al. Frontostriatal microstructure modulates efficient recruitment of cognitive control. Cereb Cortex 2006;16:553–60.
Luciana M, Nelson C. The functional emergence of prefrontally-guided working memory systems in four- to eight-year-old children. Neuropsychologia 1998;36:273–93.
Luna B, Garver KE, Urban TA, Lazar NA, Sweeney JA. Maturation of cognitive processes from late childhood to adulthood. Child Dev 2004a;75:1357–72.
Luna B, Sweeney JA. Cognitive development: fMRI studies. In: Keshavan MS, Kennedy JL, Murray RM, editors. Neurodevelopment and Schizophrenia. London: Cambridge University Press; 2004b. p. (pp. 45-68).
Luna B, Thulborn KR, Munoz DP, Merriam EP, Garver KE, Minshew NJ, et al. Maturation of widely distributed brain function subserves cognitive development. NeuroImage 2001;13:786–93.
Luna B, Velanova K, Geier CF. Development of eye-movement control. Brain Cogn 2008;68:293–308.
Marsh R, Zhu H, Schultz RT, Quackenbush G, Royal J, Skudlarski P, et al. A developmental fMRI study of self-regulatory control. Hum Brain Mapp 2006;27:848–63.
May JC, Delgado MR, Dahl RE, Stenger VA, Ryan ND, Fiez JA, et al. Event-related functional magnetic resonance imaging of reward-related brain circuitry in children and adolescents. Biol Psychiatry 2004;55:359–66.
McClure SM, York MK, Montague PR. The neural substrates of reward processing in humans: the modern role of FMRI. Neuroscientist 2004;10:260–8.
Meng SZ, Ozawa Y, Itoh M, Takashima S. Developmental and age-related changes of dopamine transporter, and dopamine D1 and D2 receptors in human basal ganglia. Brain Res 1999;843:136–44.
Middleton FA, Strick PL. Anatomical evidence for cerebellar and basal ganglia involvement in higher cognitive function. Science 1994;266:458–61.
Middleton FA, Strick PL. Basal ganglia output and cognition: evidence from anatomical, behavioral, and clinical studies. Brain Cogn 2000;42:183–200.
Middleton FA, Strick PL. Basal-ganglia 'Projections' to the prefrontal cortex of the primate. Cereb Cortex 2002;12:926–35.
Mukherjee P, McKinstry RC. Diffusion tensor imaging and tractography of human brain development. Neuroimaging Clin N Am 2006;16:19–43.
Munoz DP, Broughton JR, Goldring JE, Armstrong IT. Age-related performance of human subjects on saccadic eye movement tasks. Exp Brain Res 1998;121:391–400.
Munoz DP, Everling S. Look away: the anti-saccade task and the voluntary control of eye movement. Nat Rev Neurosci 2004;5:218–28.
Nelson CA, Monk CS, Lin J, Carver LJ, Thomas KM, Truwitt CL. Functional neuroanatomy of spatial working memory in children. Dev Psychol 2000;36:109–16.
O'Doherty JP. Reward representations and reward-related learning in the human brain: insights from neuroimaging. Curr Opin Neurobiol 2004;14:769–76.
O'Doherty J, Kringelbach ML, Rolls ET, Hornak J, Andrews C. Abstract reward and punishment representations in the human orbitofrontal cortex. Nat Neurosci 2001;4:95-102.
O'Doherty JP, Diechmann R, Critchley HD, Dolan RJ. Neural responses during anticipation of a primary taste reward. Neuron 2002;33:815–26.
Olesen PJ, Nagy Z, Westerberg H, Klingberg T. Combined analysis of DTI and fMRI data reveals a joint maturation of white and grey matter in a fronto-parietal network. Cogn Brain Res 2003;18:48–57.
Passingham D, Sakai K. The prefrontal cortex and working memory: physiology and brain imaging. Curr Opin Neurobiol 2004;14:163–8.
Paus T, Babenko V, Radil T. Development of an ability to maintain verbally instructed central gaze fixation studied in 8- to 10-year-old children. Int J Psychophysiol 1990;10:53–61.
Paus T, Zijdenbos A, Worsley K, Collins DL, Blumenthal J, Giedd JN, et al. Structural maturation of neural pathways in children and adolescents: in vivo study. Science 1999;283:1908–11.
Petit L, Courtney SM, Ungerleider LG, Haxby J. Sustained activity in the medial wall during working memory delays. J Neurosci 1998;18:9429–37.
Pfefferbaum A, Mathalon DH, Sullivan EV, Rawles JM, Zipursky RB, Lim KO. A quantitative magnetic resonance imaging study of changes in brain morphology from infancy to late adulthood. Arch Neurol 1994;51:874–87.
Pierrot-Deseilligny C, Muri RM, Ploner CJ, Gaymard B, Demeret S, Rivaud-Pechoux S. Decisional role of the dorsolateral prefrontal cortex in ocular motor behaviour. Brain 2003;126:1460–73.
Postle BR, Berger JS, Taich AM, D'Esposito M. Activity in human frontal cortex associated with spatial working memory and saccadic behavior. J Cogn Neurosci 2000;12:2-14.
Postle BR, Zarahn E, D'Esposito M. Using event-related fMRI to assess delay-period activity during performance of spatial and nonspatial working memory tasks. Brain Res Protoc 2000;5:57–66.
Reiss AL, Abrams MT, Singer HS, Ross JL, Denckla MB. Brain development, gender and IQ in children. A volumetric imaging study. Brain 1996;119:1763–74.
Resnick MD, Bearman PS, Blum RW, Bauman KE, Harris KM, Jones J, et al. Protecting adolescents from harm. Findings from the National Longitudinal Study on Adolescent Health. JAMA 1997;278:823–32.
Ridderinkhof KR, Band GPH, Logan GD. A study of adaptive behavior: effects of age and irrelevant information on the ability to inhibit one's actions. Acta Psychol 1999;101:315–37.
Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S. The role of the medial frontal cortex in cognitive control. Science 2004;306:443–7.
Ridderinkhof KR, van der Molen MW, Band GP, Bashore TR. Sources of interference from irrelevant information: a developmental study. J Exp Child Psychol 1997;65:315–41.
Roesch MR, Olson CR. Impact of expected reward on neuronal activity in prefrontal cortex, frontal and supplementary eye fields and premotor cortex. J Neurophysiol 2003;90:1766–89.
Roesch MR, Olson CR. Neuronal activity related to reward value and motivation in primate frontal cortex. Science 2004;304:307–10.
Rolls ET. The orbitofrontal cortex and reward. Cereb Cortex 2000;10:284–94.
Rosenberg DR, Lewis DA. Changes in the dopaminergic innervation of monkey prefrontal cortex during late postnatal development: a tyrosine hydroxylase immunohistochemical study. Biol Psychiatry 1994;36:272–7.
Rosenberg DR, Lewis DA. Postnatal maturation of the dopaminergic innervation of monkey prefrontal and motor cortices: a tyrosine hydroxylase immunohistochemical analysis. J Comp Neurol 1995;358:383–400.
Rubia K, Overmeyer S, Taylor E, Brammer M, Williams SC, Simmons A, et al. Functional frontalisation with age: mapping neurodevelopmental trajectories with fMRI. Neurosci Biobehav Rev 2000;24:13–9.
Rubia K, Smith AB, Woolley J, Nosarti C, Heyman I, Taylor E, et al. Progressive increase of frontostriatal brain activation from childhood to adulthood during event-related tasks of cognitive control. Hum Brain Mapp 2006;27:973–93.
Rubia K, Smith AB, Taylor E, Brammer M. Linear age-correlated functional development of right inferior fronto-striato-cerebellar networks during response inhibition and

Please cite this article as: Geier C, Luna B, The maturation of incentive processing and cognitive control, Pharmacol Biochem Behav (2008), doi:10.1016/j.pbb.2009.01.021

anterior cingulate during error-related processes. Hum Brain Mapp 2007;28: 1163–77.
Sakai K, Rowe JB, Passingham RE. Active maintenance in prefrontal area 46 creates distractor-resistant memory. Nat Neurosci 2002;5:479–584.
Scherf KS, Sweeney JA, Luna B. Brain basis of developmental change in visuospatial working memory. J Cogn Neurosci 2006;18:1045–58.
Schlaggar BL, Brown TT, Lugar HM, Visscher KM, Miezin FM, Petersen SE. Functional neuroanatomical differences between adults and school-age children in the processing of single words. Science 2002;296:1476–9.
Schultz W. Multiple reward signals in the brain. Nat Rev Neurosci 2000;1:199–207.
Schultz W. Neural coding of basic reward terms of animal learning theory, game theory, microeconomics and behavioural ecology. Curr Opin Neurobiol 2004;14:139–47.
Schultz W, Dickenson A. Neuronal coding of prediction errors. Annu Rev Neurosci 2000;23:473–500.
Schultz W, Tremblay L, Hollerman JR. Reward processing in primate orbitofrontal cortex and basal ganglia. Cereb Cortex 2000;10:272–84.
Seeman P, Bzowj NH, Fuan HC, Bergeron C, Becker LE, Reynolds GP, et al. Human brain dopamine receptors in children and aging adults. Synapse 1987;1:399–404.
Segawa M. Development of the nigrostriatal dopamine neuron and the pathways in the basal ganglia. Brain Develop 2000;22:S1-4.
Silveri MM, Tzilos GK, Pimentel PJ, Yurgelun-Todd DA. Trajectories of adolescent emotional and cognitive development: effects of sex and risk for drug use. Ann N Y Acad Sci 2004;1021:363–70.
Sowell ER, Thompson PM, Holmes CJ, Batth R, Jernigan TL, Toga AW. Localizing age-related changes in brain structure between childhood and adolescence using statistical parametric mapping. NeuroImage 1999a;9:597.
Sowell ER, Thompson PM, Holmes CJ, Jernigan TL, Toga AW. In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. Nat Neurosci 1999b;2: 859–61.
Spear LP. The adolescent brain and age-related behavioral manifestations. Neurosci Biobehav Rev 2000;24:417–63.
Steinberg L. Risk taking in adolescence: what changes, and why? Ann N Y Acad Sci 2004;1021:51–8.
Swanson HL. What develops in working memory? A life span perspective. Dev Psychol 1999;35:986-1000.
Sweeney JA, Mintun MA, Kwee S, Wiseman MB, Brown DL, Rosenberg DR, et al. Positron emission tomography study of voluntary saccadic eye movements and spatial working memory. J Neurophysiol 1996;75:454–68.
Sweeney JA, Takarae Y, Macmillan C, Luna B, Minshew NJ. Eye movements in neurodevelopmental disorders. Curr Opin Neurol 2004;17:37–42.
Takeuchi Y, Matsushita H, Sakai H, Kawano H, Yoshimoto K, Sawada T. Developmental changes in cerebrospinal fluid concentrations of monoamine-related substances revealed with a Coulochem electrode array system. J Child Neurol 2000;15:267–70.
Tamm L, Menon V, Reiss AL. Maturation of brain function associated with response inhibition. J Am Acad Child Adolesc Psych 2002;41:1231–8.
Thatcher RW, Walker RA, Giudice S. Human cerebral hemispheres develop at different rates and ages. Science 1987;236:1110–3.
Thut G, Schultz W, Roelcke U, Nienhusmeier M, Missimer J, Maguire RP, et al. Activation of the human brain by monetary reward. Neuroreport 1997;8:1225–8.
Tipper SP, Bourque TA, Anderson SH, Brehaut JC. Mechanisms of attention: a developmental study. J Exp Child Psychol 1989;48:353–78.
Toga AW, Thompson PM, Sowell ER. Mapping brain maturation. Trends Neurosci 2006;29: 148–59.
Tremblay L, Schultz W. Relative reward preference in primate orbitofrontal cortex. Nature 1999;398:704–8.
Tsujimoto S, Sawaguchi T. Neuronal activity representing temporal precition of reward in the primate prefrontal cortex. J Neurophysiol 2005;93:3687–92.
van Leijenhorst L, Crone EA, Bunge SA. Neural correlates of developmental differences in risk estimation and feedback processing. Neuropsychologia 2006;44:2158–70.
Wager TD, Smith EE. Neuroimaging studies of working memory: a meta-analysis. Cogn Affect Behav Neurosci 2003;3:255–74.
Wallis JD, Miller EK. Neuronal activity in primate dorsolateral and orbital prefrontal cortex during performance of a reward preference task. Eur J Neurosci 2003;18: 2069–81.
Wenger KK, Visscher KM, Miezin FM, Petersen SE, Schlaggar BL. Comparison of sustained and transient activity in children and adults using a mixed blocked/event-related fMRI design. NeuroImage 2004;22:975–85.
Williams BR, Ponesse JS, Schachar RJ, Logan GD, Tannock R. Development of inhibitory control across the life span. Dev Psychol 1999;35:205–13.
Wise RA. Brain reward circuitry: insights from unsensed incentives. Neuron 2002;36: 229–40.
Wise RA. Dopamine, learning and motivation. Nat Rev Neurosci 2004;5:483–94.
Yakovlev PI, Lecours AR. The myelogenetic cycles of regional maturation of the brain. In: Minkowski A, editor. Regional Development of the Brain in Early Life. Oxford: Blackwell Scientific; 1967. p. (pp. 3-70).
Yarkoni T, Braver TS, Gray JR, Green L. Prefrontal Brain Activity Predicts Temporally Extended Decision-Making Behavior. J Int Neuropsychol Soc 2005;84:537–54.
Zald DH, Iacono WG. The development of spatial working memory abilities. Develop Neuropsychol 1998;14:563–78.
Zuckerman M. Sensation seeking: beyond the optimal level of arousal. Hillsdale, NJ: Lawrence Erlbaum; 1979.
Zuckerman M. Behavioral expressions and biosocial bases of sensation seeking. New York: Cambridge University Press; 1994.

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Review article

The Teen Brain: Insights from Neuroimaging

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See Editorial p. 321

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

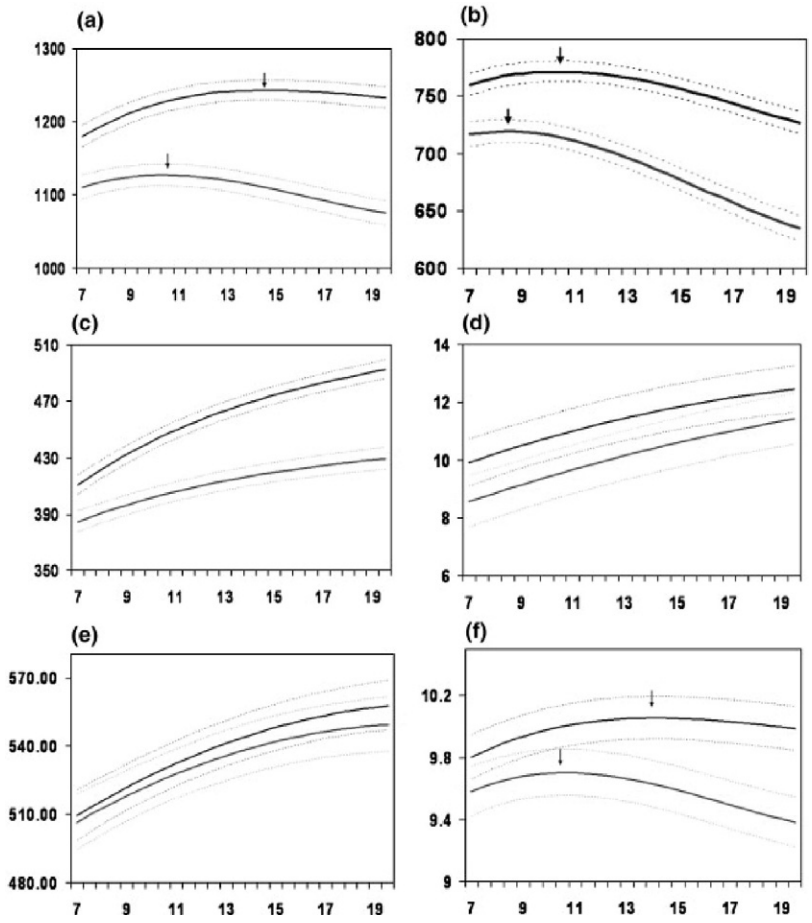

Figure 1. Mean volume by age in years for males (N = 475 scans) and females (N = 354 scans). Middle lines in each set of three lines represent mean values; upper and lower lines represent upper and lower limits of 95% confidence intervals. Arrows indicate point of peak volume. All curves differed significantly 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].

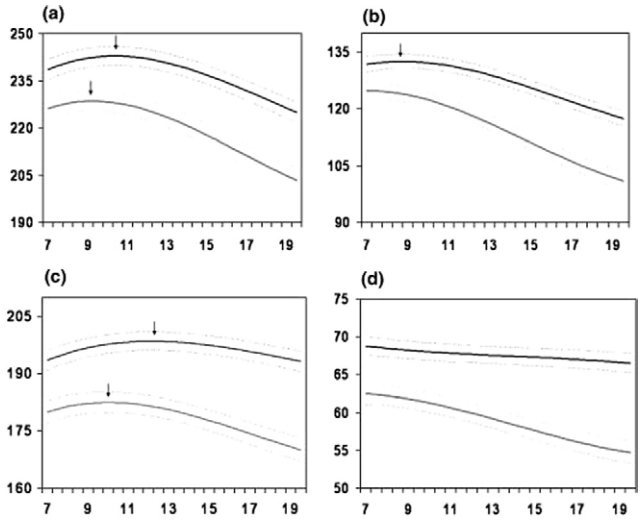

Figure 2. Gray matter subdivisions: (a) frontal lobe, (b) parietal lobe, (c) temporal lobe, and (d) occipital lobe.

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 $\epsilon 4$ group exhibiting the thinnest, the $\epsilon 3$ homozygotes in the middle range, and the $\epsilon 2$ 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.

References

[1] Lenroot RK, Gogtay N, Greenstein DK, et al. Sexual dimorphism of brain developmental trajectories during childhood and adolescence. Neuroimage 2007;36:1065–73.

[2] Dekaban AS. Tables of cranial and orbital measurements, cranial volume, and derived indexes in males and females from 7 days to 20 years of age. Ann Neurol 1977;2:485–91.

[3] Dekaban AS, Sadowsky D. Changes in brain weight during the span of human life: relation of brain weights to body heights and body weights. Ann Neurol 1978;4:345–56.

[4] Jernigan TL, Tallal P. Late childhood changes in brain morphology observable with MRI. Dev.Med Child Neurol 1990;32:379–85.

[5] Giedd JN, Snell JW, Lange N, et al. Quantitative magnetic resonance imaging of human brain development: ages 4–18. Cereb Cortex 1996;6:551–60.

[6] Goldstein JM, Seidman LJ, Horton NJ, et al. Normal sexual dimorphism of the adult human brain assessed by in vivo magnetic resonance imaging. Cereb Cortex 2001;11:490–7.

[7] Mackie S, Shaw P, Lenroot R, et al. Cerebellar development and clinical outcome in attention deficit hyperactivity disorder. Am J Psychiatry 2007;164:647–55.

[8] Middleton FA, Strick PL. Cerebellar output channels. Int Rev Neurobiol 1997;41:61–82.

[9] Desmond JE, Gabrieli JDE, Glover GH. Dissociation of frontal and cerebellar activity in a cognitive task: evidence for a distinction between selection and search. Neuroimage 1998;7:368–76.

[10] Schmahmann JD. Disorders of the cerebellum: ataxia, dysmetria of thought, and the cerebellar cognitive affective syndrome. J Neuropsychiatry Clin Neurosci 2004;16:367–78.

[11] Riva D, Giorgi C. The cerebellum contributes to higher functions during development: evidence from a series of children surgically treated for posterior fossa tumours. Brain 2000;123:1051–61.

[12] Middleton FA, Strick PL. The cerebellum: an overview. Trends Neurosci 1998;21:367–9.

[13] Middleton FA, Strick PL. Cerebellar projections to the prefrontal cortex of the primate. J Neurosci 2001;21:700–12.

[14] Lange N, Giedd JN, Castellanos FX, et al. Variability of human brain structure size: ages 4–20 years. Psychiatry Res 1997;74:1–12.

[15] Fields RD, Stevens-Graham B. New insights into neuron–glia communication. Science 2002;298:556–62.

[16] Pfefferbaum A, Mathalon DH, Sullivan EV, et al. A quantitative magnetic resonance imaging study of changes in brain morphology from infancy to late adulthood. Arch.Neurol 1994;51:874–87.

[17] Reiss AL, Abrams MT, Singer HS, et al. Brain development, gender and IQ in children. A volumetric imaging study. Brain 1996;119: 1763–74.

[18] Giedd JN, Blumenthal J, Jeffries NO, et al. Brain development during childhood and adolescence: a longitudinal MRI study. Nat Neurosci 1999;2:861–3.

[19] Giedd JN, Castellanos FX, Rajapakse JC, et al. Cerebral MRI of human brain development—ages 4–18. Biol Psychiatry 1995;37:657.

[20] Sowell ER, Thompson PM, Tessner KD, Toga AW. Mapping continued brain growth and gray matter density reduction in dorsal frontal cortex: inverse relationships during postadolescent brain maturation. J Neurosci 2001;21:8819–29.

[21] Sowell ER, Peterson BS, Thompson PM, et al. Mapping cortical change across the human life span. Nat Neurosci 2003;6:309–15.

[22] Thompson PM, Giedd JN, Woods RP, et al. Growth patterns in the developing brain detected by using continuum mechanical tensor maps. Nature 2000;404:190–3.

[23] Berlucchi G. Interhemispheric asymmetries in visual discrimination: a neurophysiological hypothesis. Doc Opthal Proc Ser 1981;30:87–93.

[24] Shanks MF, Rockel AJ, Powel TPS. The commissural fiber connections of the primary somatic sensory cortex. Brain Res 1975;98:166–71.

[25] Zaidel D, Sperry RW. Memory impairment after commissurotomy in man. Brain 1974;97:263–72.

[26] Levy J. Interhemispheric collaboration: single mindedness in the asymmetric brain. In: Best CT, editor. Hemisphere Function and Collaboration in the Child. New York: Academic Press, 1985:11–32.

[27] Cook ND. The Brain Code. Mechanisms of Information Transfer and the Role of the Corpus callosum. London: Methuen; 1986.

[28] Allen LS, Richey MF, Chai YM, Gorski RA. Sex differences in the corpus callosum of the living human being. J Neurosci 1991;11:933–42.

[29] Cowell PE, Allen LS, Zalatimo NS, Denenberg VH. A developmental study of sex and age interactions in the human corpus callosum. Dev Brain Res 1992;66:187–92.

[30] Pujol J, Vendrell P, Junque C, et al. When does human brain development end? Evidence of corpus callosum growth up to adulthood. Ann Neurol 1993;34:71–5.

[31] Rauch RA, Jinkins JR. Analysis of cross-sectional area measurements of the corpus callosum adjusted for brain size in male and female subjects from childhood to adulthood. Behav.Brain Res 1994;64:65–78.

[32] Cascio CJ, Gerig G, Piven J. Diffusion tensor imaging: application to the study of the developing brain. J Am Acad Child Adolesc Psychiatry 2007;46:213–23.

[33] Suzuki Y, Matsuzawa H, Kwee IL, Nakada T. Absolute Eigenvalue diffusion tensor analysis for human brain maturation. NMR Biomed 2003;16:257–60.

[34] Nagy Z, Westerberg H, Klingberg T. Maturation of white matter is associated with the development of cognitive functions during childhood. J Cogn Neurosci 2004;16:1227–33.

[35] Schmithorst VJ, Wilke M, Dardzinski BJ, Holland SK. Cognitive functions correlate with white matter architecture in a normal pediatric population: a diffusion tensor MRI study. Hum Brain Mapp 2005;26:139–47.

[36] Beaulieu C, Plewes C, Paulson LA, et al. Imaging brain connectivity in children with diverse reading ability. Neuroimage 2005;25:1266–71.

[37] Deutsch GK, Dougherty RF, Bammer R, et al. Children's reading performance is correlated with white matter structure measured by diffusion tensor imaging. Cortex 2005;41:354–63.

[38] Niogi SN, McCandliss BD. Left lateralized white matter microstructure accounts for individual differences in reading ability and disability. Neuropsychologia 2006;44:2178–88.

[39] Liston C, Watts R, Tottenham N, et al. Frontostriatal microstructure modulates efficient recruitment of cognitive control. Cereb Cortex 2006;16:553–60.

[40] Engelbrecht V, Rassek M, Preiss S, et al. Age-dependent changes in magnetization transfer contrast of white matter in the pediatric brain. Am J Neuroradiol 1998;19:1923–9.

[41] van Buchem MA, Steens SC, Vrooman HA, et al. Global estimation of myelination in the developing brain on the basis of magnetization transfer imaging: a preliminary study. Am J Neuroradiol 2001;22:762–6.

[42] Mukherjee P, McKinstry RC. Diffusion tensor imaging and tractography of human brain development. Neuroimaging Clin North Am 2006;16:19–43, vii.
[43] Lee KY, Kim TK, Park M, et al. Age-related changes in conventional and magnetization transfer MR imaging in elderly people: comparison with neurocognitive performance. Korean J Radiol 2004;5:96–101.
[44] Gogtay N, Giedd JN, Lusk L, et al. Dynamic mapping of human cortical development during childhood through early adulthood. Proc Natl Acad Sci U S A 2004;101:8174–9.
[45] Huttenlocher PR. Synaptogenesis in human cerebral cortex. In: Dawson G, Fischer K, editors. Human Behavior and the Developing Brain. New York: Guilford Press, 1994:137–52.
[46] Whitford TJ, Rennie CJ, Grieve SM, et al. Brain maturation in adolescence: concurrent changes in neuroanatomy and neurophysiology. Hum Brain Mapp 2007;28:228–37.
[47] Giedd JN, Shaw P, Wallace GL, et al. Anatomic brain imaging studies of normal and abnormal brain development in children and adolescents. In: Cicchetti D, editor. Developmental Psychopathology, 2nd ed.Hoboken, NJ: John Wiley & Sons, 2006:127–96.
[48] Nolte J. Olfactory and limbic systems. In: Farrell R, editor. The Human Brain. An Introduction to Its Functional Anatomy, 3rd ed. St. Louis: Mosby-Year Book, 1993:397–413.
[49] Jerslid AT. The Psychology of Adolescence, 2nd ed. New York: Macmillan, 1963.
[50] Wechsler D. Wechsler intelligence scale for children—revised. New York, Psychological Corporation, 1974.
[51] Diener E, Sandvik E, Larsen RF. Age and sex effects for affect intensity. Dev Psychol 1985;21:542–6.
[52] McGaugh JL, McIntyre CK, Power AE. Amygdala modulation of memory consolidation: interaction with other brain systems. Neurobiol Learn Mem 2002;78:539–52.
[53] Poldrack RA, Packard MG. Competition among multiple memory systems: converging evidence from animal and human brain studies. Neuropsychologia 2003;41:245–51.
[54] Giedd JN, Vaituzis AC, Hamburger SD, et al. Quantitative MRI of the temporal lobe, amygdala, and hippocampus in normal human development: ages 4–18 years. J Comp Neurol 1996;366:223–30.
[55] Clark AS, MacLusky NJ, Goldman-Rakic PS. Androgen binding and metabolism in the cerebral cortex of the deveoping rhesus monkey. Endocrinology 1988;123:932–40.
[56] Morse JK, Scheff SW, DeKosky ST. Gonadal steroids influence axonal sprouting in the hippocampal dentate gyrus: a sexually dimorphic response. Exp Neurol 1986;94:649–58.
[57] Neale MC, Cardon LR. Methodology for Genetic Studies of Twins and Families. Dordrecht, Netherlands: Kluwer Academic, 1992.
[58] Wallace GL, Schmitt JE, Lenroot RK, et al. A pediatric twin study of brain morphometry. J Child Psychol Psychiatry 2006;47:987–93.
[59] Gottesman I, Gould TD. The endophenotype concept in psychiatry: etymology and strategic intentions. Am J Psychiatry 2003;160:636–45.
[60] Schmitt JE, Wallace GL, Rosenthal MA, et al. A multivariate analysis of neuroanatomic relationships in a genetically informative pediatric sample. Neuroimage 2007;35:70–82.
[61] Rakic P. A small step for the cell, a giant leap for mankind: a hypothesis of neocortical expansion during evolution. Trends Neurosci 1995;18:383–8.
[62] Finlay BL, Darlington RB. Linked regularities in the development and evolution of mammalian brains. Science 1995;268:1578–84.
[63] Darlington RB, Dunlop SA, Finlay BL. Neural development in metatherian and eutherian mammals: variation and constraint. J Comp Neurol 1999;411:359–68.
[64] Fishell G. Regionalization in the mammalian telencephalon. Curr Opin Neurobiol 1997;7:62–9.
[65] Lenroot RK, Schmitt JE, Ordaz SJ, et al. Differences in genetic and environmental influences on the human cerebral cortex associated with development during childhood and adolescence. Hum Brain Mapp 2007;Nov 27 [Epub ahead of print].
[66] Giedd JN, Clasen LS, Wallace GL, et al. XXY (Klinefelter syndrome): a pediatric quantitative brain magnetic resonance imaging case-control study. Pediatrics 2007;119:e232–40.
[67] Merke DP, Fields JD, Keil MF, et al. Children with classic congenital adrenal hyperplasia have decreased amygdala volume: potential prenatal and postnatal hormonal effects. J Clin Endocrinol Metab 2003; 88:1760–5.
[68] Merke DP, Giedd JN, Keil MF, et al. Children experience cognitive decline despite reversal of brain atrophy one year after resolution of Cushing syndrome. J Clin Endocrinol Metab 2005;90:2531–6.
[69] Shaw P, Lerch JP, Pruessner JC, et al. Cortical morphology in children and adolescents with different apolipoprotein E gene polymorphisms: an observational study. Lancet Neurol 2007;6:494–500.
[70] Cunningham MG, Bhattacharyya S, Benes FM. Amygdalo-cortical sprouting continues into early adulthood: implications for the development of normal and abnormal function during adolescence. J Comp Neurol 2002;453:116–30.
[71] Paus T. Mapping brain maturation and cognitive development during adolescence. Trends Cogn Sci 2005;9:60–8.
[72] Huttenlocher PR, Dabholkar AS. Regional differences in synaptogenesis in human cerebral cortex. J Comp Neurol 1997;387:167–78.
[73] Huttenlocher PR, de Courten C, Garey LJ, Van Der Loos H. Synaptogenesis in human visual cortex—evidence for synapse elimination during normal development. Neurosci.Lett. 1982;33:247–52.
[74] Huttenlocher PR, de Courten C. The development of synapses in striate cortex of man. Hum Neurobiol 1987;6:1–9.
[75] Chugani HT, Phelps ME, Mazziotta JC. Positron emission tomography study of human brain functional development. Ann.Neurol 1987; 22:487–97.
[76] Thatcher RW. Maturation of the human frontal lobes: physiological evidence for staging. Dev Neuropsychol 1991;7:397–419.
[77] Benes FM. The development of prefrontal cortex: the maturation of neurotransmitter systems and their interactions. In: Nelson CA, Luciana M, editors. Handbook of Developmental Cognitive Neuroscience. Cambridge, MA: MIT Press, 2001:79–92.
[78] Rubia K, Smith AB, Woolley J, et al. Progressive increase of frontostriatal brain activation from childhood to adulthood during event-related tasks of cognitive control. Hum Brain Mapp 2006;27:973–93.
[79] Galvan A, Hare TA, Parra CE, et al. Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. J Neurosci 2006;26:6885–92.
[80] Shaw P, Greenstein D, Lerch J, et al. Intellectual ability and cortical development in children and adolescents. Nature 2006;440:676–9.
[81] Rovaris M, Iannucci G, Cercignani M, et al. Age-related changes in conventional, magnetization transfer, and diffusion-tensor MR imaging findings: study with whole-brain tissue histogram analysis. Radiology 2003;227:731–8.
[82] Collins DL, Holmes CJ, Peters TM, Evans AC. Automatic 3-D model-based neuroanatomical segmentation. Hum Brain Mapp 1995; 3:190–208.
[83] Braitenberg V. Brain size and number of neurons: an exercise in synthetic neuroanatomy. J Comput Neurosci 2001;10:71–7.
[84] Hudspeth WJ, Pribram KH. Psychophysiological indices of cerebral maturation. Int J Psychophysiol 1992;12:19–29.
[85] Courchesne E. Neurophysiological correlates of cognitive development: changes in long-latency event-related potentials from childhood to adulthood. Electroencephalogr Clin Neurophysiol 1978;45:468–82.
[86] Ladouceur CD, Dahl RE, Carter CS. ERP correlates of action monitoring in adolescence. Ann N Y Acad Sci 2004;1021:329–36.
[87] Cohen D, Cuffin BN. Demonstration of useful differences between magnetoencephalogram and electroencephalogram. Electroencephalogr Clin Neurophysiol 1983;56:38–51.