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The Teenage Brain: Self Control

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Abstract

Adolescence refers to the transition from childhood to adulthood that begins with the onset of puberty and ends with successful independence from the parent. A paradox for human adolescence is why, during a time when the individual is probably faster, stronger, of higher reasoning capacity, and more resistant to disease, there is such an increase in mortality relative to childhood. This is due not to disease but, rather, to preventable forms of death (accidental fatalities, suicide, and homicide) associated with adolescents putting themselves in harm's way, in part because of diminished *self-control*—the ability to suppress inappropriate emotions, desires, and actions. This article highlights how self-control varies as a function of age, context, and the individual and delineates its neurobiological basis.

Keywords

adolescence, prefrontal cortex, self control, ventral striatum, reward, salience, development

Introduction

During adolescence, people are probably the quickest that they will ever be; their crushes will never be better, and their thrills will never quite be the same. That's the good news. The bad news is that during this time, relative to childhood, their chances of dying from putting themselves in harm's way will increase by 200% (Dahl, 2001). This article focuses on the challenges of adolescence in the context of self-control—the ability to suppress inappropriate emotions, desires, and actions. We highlight the specific contexts in which adolescents' self-control is most likely to falter and its underlying neurobiological basis.

Over the past decade, there has been a marked increase in neurobiological research on the behavioral changes that occur during adolescence. Too often, in simplifying the findings for the media or for policymakers, this work is reduced to adolescents having no self-control and no prefrontal cortex, basically being "all gasoline, no brakes, and no steering wheel" (Bell & McBride, 2010, p. 565). Such simple claims can have positive and negative consequences for the treatment of adolescents, given that they can be used to justify both diminished responsibility for criminal acts (see Bonnie & Scott, 2013; this issue) and limited ability to make life choices (e.g., to terminate or continue a pregnancy). Reading popular science magazines that have made such claims led our group to undertake the studies of self-control described in this article. Here, we present our work in the context of three common "myths" or overgeneralizations about adolescence to clarify and temper some of these claims.

The first is that adolescent behavior is irrational or deviant. Such descriptions may be understandable in light of the peak incidence in criminal activity and many psychiatric disorders that arise during this developmental period. Yet this description pathologizes an important phase of normal development that allows individuals to learn how to function relatively independently in society. A second overgeneralization is that adolescents are incapable of making rational decisions because of their immature prefrontal cortex (Yurgelun-Todd, 2007), the so-called rational, vulcanized region of the brain (J. D. Cohen, 2005). Clearly, the prefrontal cortex is not the only part of the brain that changes during this developmental period, and the child's prefrontal cortex is even less mature than the adolescent's. Thus, this explanation does not sufficiently explain spikes in risky and emotive behavior during adolescence. We present evidence that underscores the importance of considering brain regions as part of a developing circuitry that is fine-tuned with experience during this time. Third is the century-old claim that all adolescents experience

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"sturm und drang"—that is, "storm and stress"—a claim originally proposed by G. Stanley Hall (Hall, 1904). Although adolescents show poor self-control as a group, we provide evidence for when self-control is most likely to break down during adolescence and for striking individual differences in this ability across the life span that may put some teens at greater risk than others. We address each of the preceding overgeneralizations in the context of a neurodevelopmental framework.

Self-Control and the Teenage Brain

Overgeneralization 1: Adolescents are incapable of making optimal decisions

Adolescence, by definition, involves new demands on the individual as she or he moves from dependence on the family unit to relative independence. This developmental period is not specific to humans, as evidenced by the increases in novelty seeking, interactions with peers, and fighting with parents observed in other species (see Romeo, 2013; Spear, 2013; both in this issue). These behaviors are thought to have evolved to serve adaptive functions related to successful mating and obtainment of resources necessary for survival (Spear & Varlinskaya, 2010). A heightened sensitivity to socially relevant cues (e.g., peers, monetary gain) would seem to be an ideal mechanism for meeting some of these developmental challenges. However, such a system may appear less than optimal when the pull by these socially relevant cues comes at the expense of long-term goals and the overall well-being of the adolescent.

To suggest that this period of development is one of no brakes or steering wheel (Bell & McBride, 2010) is to greatly oversimplify it. In a series of recent experiments in our laboratory (Somerville, Hare, & Casey, 2011), we measured self-control using a variant of a go/no-go paradigm that contained social cues (positive, negative, or neutral facial expressions). By using socially relevant and emotionally salient stimuli together with neutral stimuli, we could test how well adolescents regulated their impulses in both emotional and nonemotional contexts (Hare et al., 2008; Somerville et al., 2011).

Self-control—in this case, suppressing a compelling action—showed a different developmental pattern in the context of emotional information than in its absence, especially for males (Tottenham, Hare, & Casey, 2011). As illustrated in Figure 1 (also see Fig. 1 in Hare et al., 2008; National Research Council, 2011), when no emotional information is present, not only do many adolescents perform as well as adults, some perform even better. However, when decisions are required in the heat of the moment (i.e., in the presence of emotional cues; Fig. 2a), performance falters (Fig. 2b). Specifically, adolescents have difficulty suppressing a response to appetitive social cues relative to neutral ones. This diminished ability is not observed in children and adults,

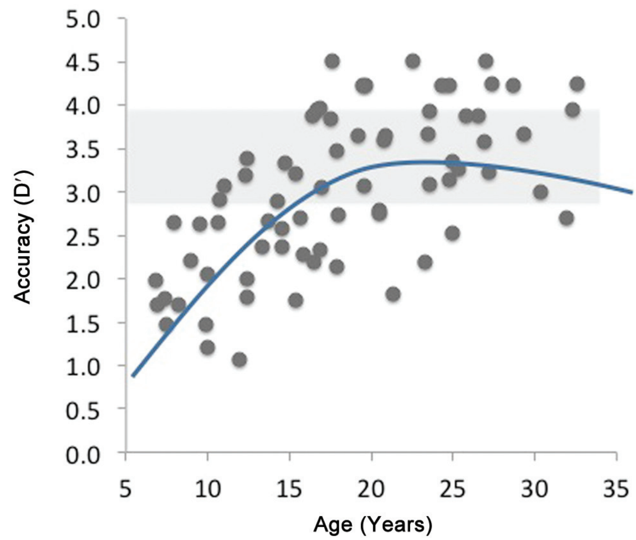

Fig. 1. Performance on a standard go/no-go task as a function of age. D′ was used as a measure of accuracy that includes both hits and false alarms. The data illustrate improvements in performance with age but also high variability, with some adolescents performing as well as or better than some adults (highlighted by the gray box). Data are drawn from Hare et al. (2008) and National Research Council (2011).

who show equal difficulty in suppressing responses regardless of the emotional content of the nontarget. Thus, the description of teens as "all gasoline, no brakes, and no steering wheel" more accurately reflects their behavior in heated situations than in cool, less immediate, and less emotional ones. In these cool situations, the teen appears to be capable of acting rationally and making optimal decisions.

Overgeneralization 2: Adolescents have no prefrontal cortex

Saying that one studies the adolescent brain is often met with comic skepticism and feigned relief that adolescents do indeed have a brain. There is no hole in the head or absence of parts to suggest a lesion-related impairment during this period. Moreover, the prefrontal cortex, a region important in self-control and rational decision making, is clearly present even from birth. What is changing during this period of development is the strength of connections within prefrontal circuitry as individuals learn to adapt to changing environmental demands (Liston et al., 2006). This development reflects a combination of evolutionarily shaped biological constraints and experiential history, which interact to shape the brain and behavior.

Evidence from human imaging and animal studies of regional neurochemical, structural, and functional brain changes over the course of development have led to a theoretical account of adolescence referred to as the *imbalance*

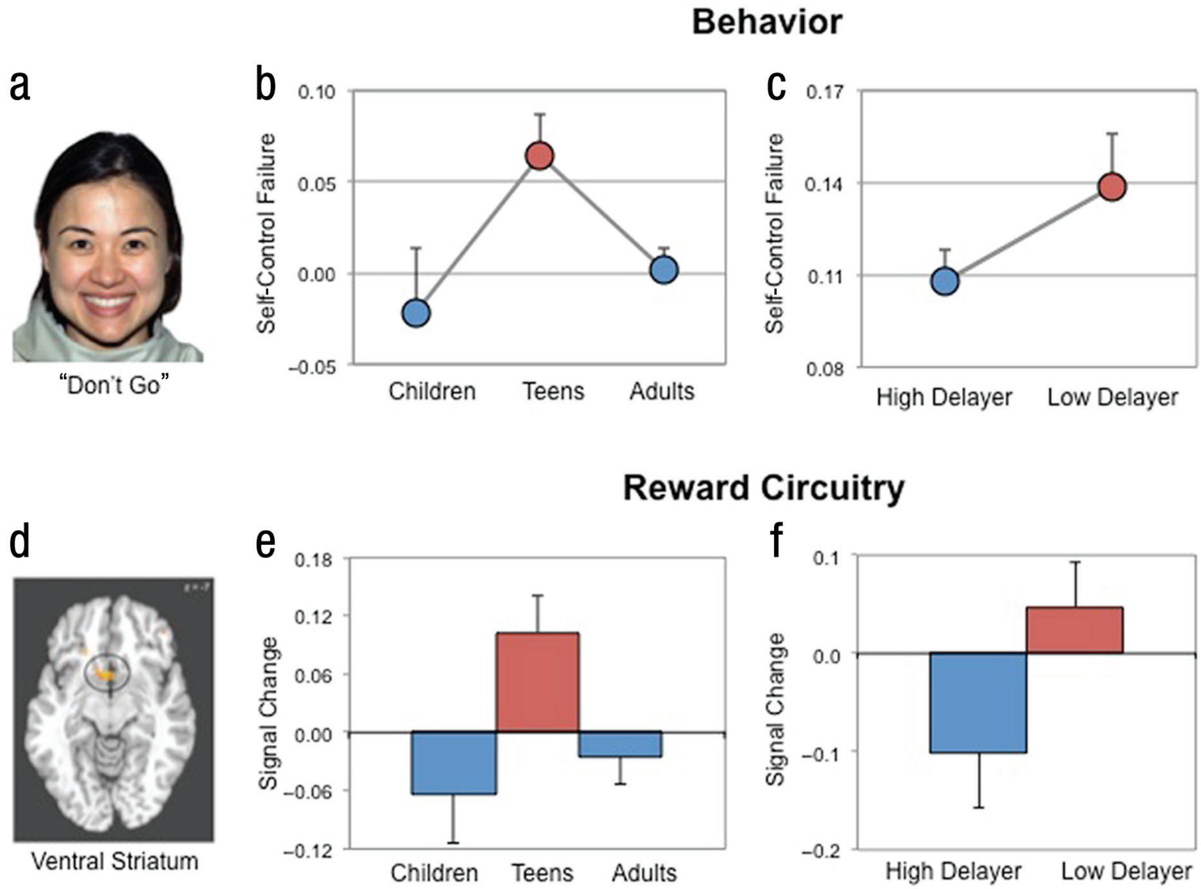

Fig. 2. Developmental and individual differences in behavior and the brain. Teens, unlike children and adults, make more false alarms to positive social cues (a) than to neutral ones on a go/no-go task. This behavioral performance (b) is paralleled by enhanced activity in the ventral striatum (d), part of the reward circuit, in response to appetitive cues in teens relative to children and adults (e). Low delayers make more false alarms to positive social cues than do high delayers on a go/no-go task (c). This behavioral performance is paralleled by enhanced activity of the ventral striatum in low delayers relative to high delayers (f). Error bars represent ±1 *SE*. Data are drawn from Somerville, Hare, and Casey (2011) and Casey et al. (2011).

model of brain development (Somerville & Casey, 2010). According to this view, reward-related subcortical regions and prefrontal control regions interact differently across development. Specifically, motivational and emotional subcortical connections develop earlier than do connections supporting prefrontal control. This developmental imbalance results in a relatively greater reliance on motivational subcortical regions than on prefrontal regions during adolescence (i.e., an imbalance in reliance on different systems), as compared with adulthood, when this circuitry is fully mature, and also as compared with childhood, when this circuitry is still developing. With age and experience, the connectivity between these regions is strengthened and provides a mechanism for top-down modulation of the subcortically driven emotional behavior that increases the capacity for self-control.

Recently, a number of human imaging studies have attempted to evaluate this model and test for unique patterns of brain activity in adolescents during stereotypical risky behavior in the context of incentives (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; J. R. Cohen et al., 2010; Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010; Van Leijenhorst et al., 2010). This work has challenged the view that diminished self-control in adolescents is due to a less mature prefrontal cortex that leads to less successful exertion of regulatory control on behavior (Bell & McBride, 2010). In contrast, these studies have revealed a unique sensitivity to motivational cues during adolescence that appears to challenge the less mature cognitive control systems when called upon simultaneously in tasks that involve inhibiting attention or actions toward potential incentives. Accordingly, developmental differences in self-control arise because of maturational constraints of developing brain circuitry and the strengthening of the connectivity between these interacting brain systems with experience (Liston et al., 2006).

To better understand changes in self-control during adolescence, we used functional brain imaging together with our previously described go/no-go task. Specifically, we examined the neural correlates of self-control in the face of emotional and nonemotional cues. We found that the ability to suppress a habitual response, regardless of emotional content, relied on the ventrolateral prefrontal cortex (Fig. 3). Activity in this region showed a monotonic increase with age for correct trials that was correlated with behavioral performance. In contrast, the ability to suppress a response to emotional cues revealed a different pattern of brain activity. Specifically, diminished behavioral performance by adolescents in suppressing responses to positive emotional cues was paralleled by enhanced activity in the ventral striatum (Fig. 2d and 2e), a region critical for detecting and learning about novel and rewarding cues in the environment. These findings suggest an exaggerated ventral-striatal representation of appetitive cues in adolescents that may serve to "hijack" a less fully mature prefrontal control response. Thus, adolescents' decisions and actions are not due solely to a less mature prefrontal cortex but, rather, to a tension within neural circuitry involving the ventral striatum, implicated in reward processing, and the prefrontal cortex, implicated in control processing.

Overgeneralization 3: All adolescents experience similar degrees of storm and stress

Nearly everyone reading this article survived adolescence reasonably well. Clearly, we are not all doomed during adolescence, as was suggested by G. Stanley Hall's theory of adolescence (Hall, 1904). Rather, adolescence falls somewhere between the extreme views of Hall's storm-and-stress theory of adolescence and Margaret Mead's cultural–not-biological account of adolescence (Mead, 1928). Basically, our behavior is a reflection of environmental and genetic factors that impact our brain's ability to adapt to changing environmental demands. Some environmental demands are universally expected, and some are specific to an individual's experiences. How well we adapt to these changing environmental demands is a function of biological constraints and experiential history. Thus, even as adults, we may differ in our ability to face new challenges and to adequately regulate our behavior accordingly.

A hallmark of self-regulation is the ability to resist the temptation of an immediate reward in favor of a larger reward later, known as *delay of gratification*. A classic paradigm for assessing this ability was developed by Mischel (Mischel, Shoda, & Rodriguez, 1989) for use with young children. He examined whether children would choose a small reward (one marshmallow) sooner over a larger reward (two marshmallows) later. Children's behavior fell into two clusters: (a) they ate the treat almost immediately (low delayers), or (b) they waited for some amount of time in an attempt to gain two treats (high delayers). These two different patterns of behavior provide an example of individual differences in self-control that can be detected and measured in early childhood (Mischel et al., 1989). However, how did these individuals fare in their self-control ability later in life?

To address this question, we recently examined self-control in a 40-year follow-up of the original cohort of children Mischel tested on the delay-of-gratification task. Using both neutral ("cool") and emotional ("hot") cues in a go/no-go

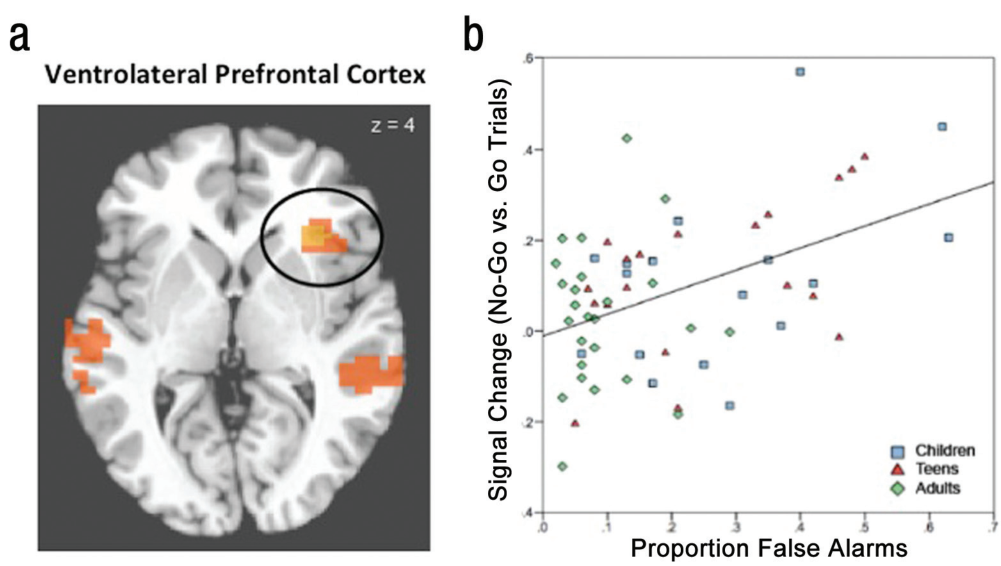

Fig. 3. Correlation of ventral prefrontal activity with go/no-go task performance. Panel (a) illustrates localization of the ventral prefrontal cortical region that correlates with behavioral performance. Panel (b) illustrates the correlation between blood-oxygen-level-dependent (BOLD) signal in the ventral lateral prefrontal cortex and go/no-go task performance by age group. Adapted from "Frontostriatal Maturation Predicts Cognitive Control Failure to Appetitive Cues in Adolescents," by L. H. Somerville, T. Hare, and B. J. Casey, 2011, *Journal of Cognitive Neuroscience*, *23*. Copyright 2011 by the Society for Neuroscience. Adapted with permission.

task, we examined the ability of these individuals, now in their mid-40s, to suppress habitual responses to emotional or neutral cues. Because marshmallows do not have quite the same appeal for adults as they do for children, we used social cues (e.g., happy faces relative to neutral and fearful faces) rather than marshmallows as nontargets in a go/no-go task.

The results indicated that even 40 years later, the same individuals who could not stop themselves from immediately eating the marshmallow and thus kept themselves from getting two marshmallows also had difficulty suppressing their responses when a positive social cue was present, even when they were instructed not to respond (Fig. 2c). However, they had no problem suppressing habitual responses to neutral cues (Casey et al., 2011). Thus, individuals who, as a group, had more difficulty delaying gratification at 4 years of age continued to show reduced self-control 40 years later. These findings highlight individual differences in self-control that are independent of age and can persist throughout the life span. However, a remaining question is whether the neural correlates underlying individual differences in self-control are similar to those observed in adolescents in our previously described study.

To address this question, high- and low-delaying individuals were imaged during performance of the "hot" go/no-go task (Casey et al., 2011). The findings showed that whereas prefrontal activity was associated with accurately withholding a response, activity in the ventral striatum mapped onto the behavioral finding of poorer performance when specifically suppressing a response to an appetitive social cue (Fig. 2f).

These findings underscore the importance of the stimulus qualities a person has to resist in an act of self-control. Sensitivity to characteristics of environmental cues (e.g., salience, reward value) can significantly influence an individual's ability to suppress inappropriate actions in favor of appropriate ones. This tension between regulation of behavior and sensitivity to positive environmental cues in many ways parallels observations from our adolescent study (Somerville et al., 2011). Perhaps unsurprisingly, children's ability to delay gratification at 4 years of age predicts parental ratings of these individuals' self-control during adolescence, too (Mischel, Shoda, & Peake, 1988). Both examples show how stimulus qualities such as rare, positive social cues can compromise an individual's self-control and suggest that both developmental and individual differences affect this ability. Thus, individuals who have diminished self-control may be especially vulnerable during adolescence, when a heightened sensitivity to emotional environmental cues can further hinder this ability.

Discussion

Our findings suggest that adolescents can show remarkable restraint in controlling habitual responses but tend to fail when attempting to control habitual responses to salient positive cues in the environment. Specifically, we showed that adolescents have impulse control that is comparable to or even better than that of some adults in neutral contexts (Fig. 1). However, in emotional contexts, adolescents' impulse-control ability is severely taxed relative to that of children and adults (Fig. 3). This behavioral pattern is paralleled by exaggerated responses in reward-related circuitry that presumably are difficult to regulate because of less top-down control from still-developing prefrontal connections in teenagers. This tension between motivational and control processes during adolescence can vary by individual, leading to enhanced or diminished self-control. To say that the adolescent is "all gasoline, no brakes, and no steering wheel" is to do a disservice to this essential phase of typical development. Indeed, if the objective of adolescence is to gain independence from the family unit, then providing opportunities for adolescents to engage in new responsibilities is essential. Without opportunities and experiences to help optimally shape the adolescent's brain and behavior, the objectives of this developmental phase will not easily be met.

Recommended Reading

Casey, B. J., Duhoux, S., & Cohen, M. M. (2010). Adolescence: What do transmission, transition, and translation have to do with it? *Neuron, 67*, 749–760. A review highlighting the fact that adolescence is not special to humans but, rather, is an evolutionarily adaptive and necessary phase of typical development that is observed across species.

Casey, B. J., Somerville, L. H., Gotlib, I. H., Ayduk, O., Franklin, N. T., Askren, M. K., . . . Shoda, Y. (2011). (See References). A study providing empirical evidence of stable individual differences in self-control over 40 years that are associated with differences in ventral frontostriatal circuitry.

Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). (See References). An article emphasizing the role that peers play in adolescent decision making and highlighting the ventral striatum as a brain region through which the presence of peers influences risky decision making in adolescence.

Cohen, J. R., Asarnow, R. F., Sabb, F. W., Bilder, R. M., Bookheimer, S. Y., Knowlton, B. J., & Poldrack, R. A. (2010). (See References). A study that provides empirical evidence that adolescents, relative to children and adults, respond more quickly to stimuli associated with large rewards and a greater positive prediction error in the ventral striatum, and discusses how adolescent decision making and behavior may be understood using quantitative behavioral decision-making approaches.

Geier, C. F., Terwilliger, R., Teslovich, T., Velanova, K., & Luna, B. (2010). (See References). A study using an antisaccade task that demonstrates how reward motivation dynamically influences recruitment of striatal and prefrontal regions in adolescents.

Somerville, L. H., Hare, T., & Casey, B. J. (2011). (See References). A study providing empirical evidence showing that adolescents can show remarkable restraint in controlling habitual responses

but tend to fail when attempting to control habitual response to salient positive cues in the environment—a behavioral pattern paralleled by exaggerated responses in reward-related circuitry relative to children and adults.

Van Leijenhorst, L., Zanolie, K., Van Meel, C. S., Westenberg, P. M., Rombouts, S. A., & Crone, E. A. (2010). (See References). A report from a study using a passive-viewing gambling task of striatal and prefrontal regions that are more sensitive to the anticipation and receipt of rewards in adolescence.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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