Self-Control and the Developing Brain

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A 4-year-old sits at a table with one piece of candy in front of him. He is told that if he does not touch the candy, he can have not one but two pieces of candy in a few minutes. Will he be able to control his impulse to reach for the candy and wait for the larger reward instead? Self-control is critical to success at home, at school, and with friends. A child with good self-control can refrain from hitting another child when there is a conflict, pay attention to the teacher's lecture instead of talking over it, and wait his turn when playing a game. Self-control in young children predicts school readiness, academic achievement, social competence, and appropriate conduct (Eisenberg, Hofer, & Vaughan, 2007; W. Mischel, Shoda, & Peake, 1988). Deficits in self-control are defining features of attention and behavior disorders, including attention-deficit/hyperactivity disorder (ADHD) and conduct disorder (Barkley, 1997; White et al., 1994). When self-control deficits persist into adulthood, they are associated with interpersonal problems, poor physical health, and psychiatric disorders (Strayhorn, 2002). Thus, the development of self-control has implications for many child outcomes.

As every parent and early childhood educator can attest, self-control takes a long time to develop. Infants have a few basic self-control strategies; for example, by about 3 months of age they can look away from a social interaction when they need a break to avoid becoming overstimulated or distressed (Harman, Rothbart, & Posner, 1997). For the most part, though, from birth to 3 years, children rely heavily on parents and caregivers to help them control their emotions and behavior. Three to 6 years marks a renaissance period in the development of self-control, including the abilities to control impulses, shift attention from one thing to another, and wait for a reward (Diamond & Taylor, 1996; Lewis & Todd, 2007; H. N. Mischel & Mischel, 1983; Thompson, Barresi, & Moore, 1997). Self-control skills continue to develop throughout childhood and adolescence. The brain regions involved in self-control are immature at birth and are not fully mature until the end of adolescence, which helps to explain why developing self-control is such a long, slow process.

Even though self-control increases with age, there are marked differences among children of the same age. Although one 4-year-old might wait patiently for the candy reward, another 4-year-old might grab the candy immediately. This impulsive child is also likely to strike out at peers when frustrated and to have trouble paying attention at school. In consistent environments, these individual differences are fairly stable—toddlers and preschoolers who have difficulty with self-control compared with their peers are likely to continue to have poor self-control as school-age children (Cummings, Iannotti, & Zahn-Waxler, 1989; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). A brain-based approach to studying self-control can shed light on the environmental and genetic contributions to individual differences, suggest why children with certain environmental risk factors are more likely to develop self-control problems, and guide the development of training programs designed to target brain regions involved in self-control.

Self-Control in the Brain

Brain development is not exclusively due to the passage of time, as if the brain had an internal clock and was changing and growing automatically on a certain schedule. Although the brain does change with age, the child's experiences play an active role in shaping the brain as it develops and in building connections between different parts of the brain. Several brain regions support the skills relevant to self-control. For effective self-control, these regions all need to be interconnected and must communicate with each other. The child's behavior is determined by a system of checks and balances between different parts of the brain working together.

An important region for self-control is the *prefrontal cortex*, located just behind the

Abstract

Self-control is a skill that children need to succeed academically, socially, and emotionally. Brain regions essential to self-control are immature at birth and develop slowly throughout childhood. From ages 3 to 6 years, as these brain regions become more mature, children show improved ability to control impulses, shift their attention flexibly, and wait for a reward. Early childhood environment helps to shape self-control pathways in the developing brain. Children who experience early adversity are at risk for self-control problems. Preschool curricula and specialized training programs to promote the development of self-control offer promise as an intervention for at-risk children.

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Predictable routines can support children's emerging self-control capacities.

forehead (see Glossary box). One of the biggest differences between human brains and monkey brains is the size of the prefrontal cortex, which is much larger in humans. It is involved in complex attentional and organizational skills, including following rules, reasoning, suppressing impulses, and making decisions (Casey et al., 1997). Neuroimaging studies show that the prefrontal cortex develops gradually from infancy through adolescence (Gogtay et al., 2004). The *orbitofrontal cortex* is located just behind the eyes and also is involved in decision making, especially when the decision involves reward, as in the example of waiting for candy (Zelazo, Carlson, & Kesek, 2008; see Figure 1, and see Glossary box).

For young children, one of the hardest aspects of self-control is resisting an emotional impulse—for example, refraining from grabbing the candy despite wanting it or refraining from hitting a peer despite feeling angry. Children may know the rules and be able to think about them logically, but they still may be unable to resist their impulse. For example, 3-year-olds will advise an experimenter that it would be in the experimenter's best interest to wait for a larger candy reward. However, when the 3-year-olds are presented with the candy, the emotional impulse wins, and they grab the candy right away. Clearly they know logically that it is better to wait, but just knowing this isn't enough (Prencipe & Zelazo, 2005). One brain region that plays a critical role in balancing out logical thought and emotional impulses is the *anterior cingulate* (see Glossary box). The anterior cingulate is sandwiched between the prefrontal cortex and areas deep inside the brain involved in emotional responses. The anterior cingulate receives messages from many brain regions and integrates all of the information to regulate both cognitive and emotional processes (Zelazo et al., 2008). It is involved in controlling behavior in challenging situations and making adjustments to behavior when a strategy is not working (Luu & Tucker, 2002). The top part of the anterior cingulate, which receives messages from the prefrontal cortex, becomes more active from ages 3 to 6 years, and it is during this same developmental period that children become better able to wait for a reward and to suppress impulsive behaviors (Posner & Rothbart, 2000). The logical frontal part of the brain becomes more capable of exerting control over the emotional, impulsive part of the brain, at least some of the time.

Glossary

Anterior cingulate — An area of the brain sandwiched between the frontal lobe and emotion-related brain regions. The anterior cingulate integrates cognition with emotional impulses, controls behavior in challenging situations, and adjusts behavior when a strategy is not working.

Orbitofrontal cortex — An area of the brain located behind the eyes, involved in decision making and reward.

Prefrontal cortex — An area of the brain located behind the forehead that is involved in higher level attention and cognition, following rules, suppressing an impulse, reasoning, and decision making.

A particular characteristic brain-wave pattern is thought to reflect activity of the anterior cingulate (van Veen & Carter, 2002). By placing a cap on the child's head that has sensors to record electrical activity, studies have measured brain-wave changes in response to presentation of a stimulus. Using this measure, called the *event-related potential* (ERP), studies have revealed evidence that the anterior cingulate is active during self-control tasks. In 4- to 6-year-old children, these characteristic brain-wave changes are observed while children are engaged in computer tasks that involve self-control, such as resisting the impulse to push a button that would make an angry face go away (Lewis & Todd, 2007). Four-year-olds show these brain-wave changes all over the frontal lobe while they are resisting an impulse, suggesting that widespread areas of the brain are recruited to try to resist the impulse. It is interesting to note that in adults the change in recorded brain waves when resisting an impulse is focused on a much smaller area of the brain. It seems that the brain gets more efficient at exerting self-control over the course of development (Rueda, Posner, & Rothbart, 2005).

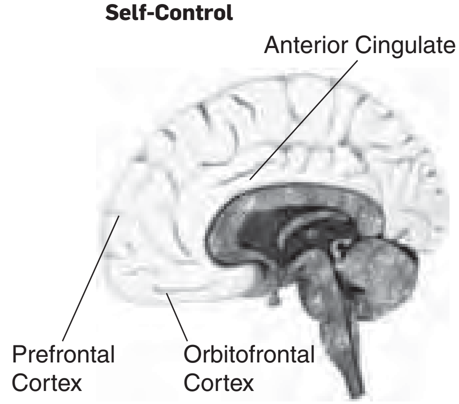
Individual Differences in Self-Control

Why do some children have better self-control than other children of the same age? The environment where the child grows up, temperament, and genes all influence the development of self-control. These various factors do not operate in a vacuum but interact with each other to contribute to individual differences in self-control.

Family and Culture

Although infants and toddlers do not have much self-control yet, the home environ-

Figure 1. Brain Regions Involved in Self-Control



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A child's behavior is determined by different parts of the brain working together.

ment and caregiver relationships from birth to 3 years help to shape self-control abilities. Infant attachment security predicts self-control 6 years later (Olson, Bates, & Bayles, 1990). When 18-month-old toddlers were placed in frustrating situations, such as having an attractive toy placed beyond their reach, the toddlers whose mothers had a more intrusive style tended to become more distressed. In contrast, toddlers whose mothers provided positive guidance were better able to distract themselves (Calkins & Johnson, 1998). In another study, when mothers (a) were sensitive and responsive with their 1-year-old infants, (b) talked about emotions and other mental states, and (c) were supportive while also encouraging independence, the infants went on to do better on attention and self-control tasks 6 to 12 months later (Bernier, Carlson, & Whipple, in press). Sensitive parenting in early childhood that supports autonomy helps children to develop self-control strategies.

The home environment from infancy through age 5 years, including both caregiver relationship quality and the physical and social resources available in the home, predicts self-control abilities in first grade (National Institute of Child Health and Human Development [NICHD] Early Child Care Research Network, 2005). In middle childhood, negative parenting continues to relate to poorer child self-control over time, and the reverse is also true: Poorer child self-control can elicit more negative parenting. In this way, maladaptive interaction patterns can become entrenched, putting children at higher risk of behavior problems (Eisenberg et al., 1999). Experience with multiple languages also can affect the development of self-control. Bilingual children do better than monolingual children on attention-control tasks that require shifting attention from one feature to another, such as sorting cards according to color and then switching gears to sort the cards according to shape (Bialystok & Martin, 2004). Switching back and forth between languages may help bilingual children learn to think flexibly and shift their attention (Zelazo et al., 2008). This is an example of how developing brain regions involved in attentional control, including the anterior cingulate and prefrontal cortex, may be shaped by the child's experiences.

Children growing up in cultures that place a high emphasis on the importance of self-control tend to develop self-control abilities faster. Korean preschools typically have formal instruction, long periods of sitting still, and little free play. Chinese preschools are also highly structured and provide many opportunities to practice self-control, such as group activities in which everyone draws the same picture. Both Korean and Chinese

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One of the most difficult aspects of self-control is resisting an emotional impulse.

preschool children perform better than their U.S. peers on self-control tasks (Oh & Lewis, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006). The highly structured environment may help self-control brain circuits mature faster. The high cultural value placed on self-control may also motivate Chinese and Korean children to exert more self-control.

Within U.S. culture, developmentally appropriate preschool programs also are designed to scaffold children's emerging self-control capacities through predictable routines; songs such as the "Clean Up Song" that help children remember and follow classroom rules; games like Simon Says that exercise developing self-control brain circuits; and opportunities for children to make choices (i.e., practice planning skills) among safe and permissible alternatives (Gillespie & Seibel, 2006).

Temperament

When presented with an unfamiliar toy, some infants may be fearful and cautious, whereas others are eager to reach for it without hesitation. These temperamental differences are brain based. Individuals who have more brain activity occurring in the left frontal area of their brain tend to be eager to approach and explore unfamiliar situations and objects. In contrast, those who have more activity in the right frontal area tend to (a) avoid unfamiliar situations and objects and (b) be more fearful, cautious, and easily distressed (Sutton & Davidson, 1997).

Fearful or cautious temperament in early childhood predicts the development of better self-control. Infants who were more cautious in response to an unfamiliar toy, looking at it for a long time before reaching for it, tended to have better self-control at age 7 years (Rothbart, Derryberry, & Hershey, 2000). In another study (Aksan & Kochanska, 2004), response to unfamiliar objects and situations was assessed in infancy by using masks and in the toddler years also by observing the child's behavior in a *risk room*. The risk room included potentially "risky" unfamiliar objects such as a tunnel, a balance beam, and stairs from which the child could leap onto a mattress if she chose to do so. Children who were more fearful and cautious in response to the masks and risk room as infants and toddlers tended to be less impulsive as preschoolers and better at self-control games such as Simon Says (Aksan & Kochanska, 2004).

So far, the self-control problems to which we have referred have involved *undercontrol*: children who are impulsive and prone to acting out. However, the other extreme, being *overcontrolled*, may also interfere with children's functioning. Studies of the interaction of temperament and self-control have shown that when it comes to self-control, more is not always better. Among 2-year-olds with an exuberant temperament, those with high self-control were also rated as more socially competent. In contrast, among shy 2-year-olds, high self-control was related to being more socially withdrawn and less socially competent (Fox, Henderson, Perez-Edgar, & White, 2008). Fox et al. (2008) suggested that for a child to be well-adjusted, a balance of emotional reactivity and self-control is needed. Some researchers have moved toward using the term "self-regulation" rather than self-control, to reflect this idea that healthy control means knowing when to exert control and when to loosen up.

Sensitive parenting in early childhood helps children develop self-control.

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Genetics

The study of genes involved in self-control is a relatively new area of inquiry. So far, several genes have been identified that are related to performance on self-control tasks, particularly tasks that measure ability to focus attention, suppress impulses, and ignore distractions. All of these genes affect levels of the brain chemical *dopamine*, which influences the functioning of the prefrontal cortex and the anterior cingulate. The genes each have multiple versions, called *alleles*, and different children inherit different versions. Six-year-olds with the long version of a gene called DAT1 were reported by their parents to have better self-control and less impulsive behavior, did better on a laboratory attention-control task, and showed a more mature pattern of brain activity while doing the task compared with 6-year-olds with the short version of DAT1 (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). For several other dopamine-related genes, the pattern of brain-wave activity while children are performing an attention-control task varies depending on which version of the gene a child has (Diamond, Briand, Fossella, & Gehlbach, 2004; Fossella et al., 2002). One of these same genes, called the DRD4 gene, has a version that is also associated with higher risk of ADHD and attention-seeking behavior.

The relation between a particular version of a gene and self-control behavior can be influenced by the child's environment. For example, as previously mentioned, Chinese preschools tend to be structured in a way that places more emphasis on self-control compared with most U.S. preschools. However, there is also a genetic contribution. The at-risk version of the DRD4 gene occurs in 48% of the White U.S. population, compared with only 2% of the Chinese population (Sabbagh et al., 2006). Therefore, the high self-control in Chinese preschoolers may reflect not only an environment that supports developing self-control but also lower genetic risk for self-control problems. In another example, among physically maltreated children, those who had a particular version of the dopamine-related gene MAOA were less likely to develop severe behavior problems than those who had another version (Caspi et al., 2002). More research is needed to investigate the different ways that multiple genetic and environmental factors interact to influence the development of self-control.

Children at Risk for Self-Control Problems

Exposure to alcohol or drugs in the prenatal environment affects the developing brain and puts children at risk for self-control problems. Heavy prenatal alcohol exposure can lead to structural abnormalities in the orbitofrontal cortex and other brain regions involved in self-control. Prenatal alcohol exposure has been linked to self-control deficits, impulsivity, and increased rates of an ADHD diagnosis (Mattson, Fryer, McGee, & Riley, 2008). Prenatal cocaine exposure affects the development of the anterior cingulate and the prefrontal cortex. In particular, prenatal and perinatal cocaine exposure appears to permanently distort the balance of brain chemicals in the prefrontal cortex (Langlois & Mayes, 2008). Children with a history of prenatal cocaine exposure tend to have poor impulse control, greater emotional reactivity, and difficulty sustaining attention.

Maltreated and neglected children are also vulnerable to self-control problems. In a neglectful environment, young children lack the opportunity to learn self-control strategies from interacting with caregivers (Shackman, Wismer Fries, & Pollak, 2008). When the brain develops in neglectful environments, it is deprived of appropriate experiences to shape the development of self-control circuits. Physically abused children tend to have difficulty controlling their emotions. In one study, problems in attentional control accounted for the link between maltreatment and difficulties regulating emotion (Shields & Cicchetti, 1998). Shields and Cicchetti concluded that these physically abused children lacked the attentional strategies to control their emotional impulses.

Preschool and early school-age children who grow up in poverty score lower than middle-class children on a variety of self-control tasks (Howse, Lange, Farran, & Boyles, 2003; Lengua, Honorado, & Bush, 2007). The more demographic and environmental risk factors a preschool child experiences, the more likely he or she is to have difficulty with self-control (Lengua et al., 2007; Li-Grining, 2007). Using tasks that neuroimaging studies have demonstrated to involve specific brain areas, researchers can identify specific areas of deficit. For example, the Go-NoGo task requires pushing a button every time a letter flashes on the screen, *except* for the letter X. Functional magnetic resonance imaging (fMRI) scans taken while children are engaged in the Go-NoGo task show that the prefrontal cortex "lights up," indicating that it is involved in this task (Casey et al., 1997). On self-control tasks that have been shown through these methods to involve the prefrontal cortex and anterior cingulate, kindergartners from low-income families have lower scores than their middle-class peers (Noble, Norman, & Farah, 2005), and this socioeconomic difference also is observed in preadolescents (Farah et al., 2006).

Sleep disruption may be one reason that children living in poverty often have self-control difficulties. Families living in poverty may experience sleep disruption because of overcrowded households, chronic stress, hunger, and poor temperature control in the sleep environment. Lower socioeconomic status has been linked to increased rates of sleep problems in children (Buckhalt, El-Sheikh, & Keller, 2007). Attention-control tasks that involve the prefrontal cortex are sensitive to sleep (Dahl, 1996). When children do not get a good night's sleep, self-control is often impaired the next day. A study of second graders revealed that disrupted sleep was associated with poorer performance on attention-control tasks and with parent report of behavior problems (Sadeh, Gruber, & Raviv, 2002). Although these studies establish that current sleep deprivation puts children at risk for temporary self-control difficulties, it is unclear whether chronic sleep deprivation has long-term impacts on development of self-control.

Children reared in poverty and maltreated children are at increased risk for problems in many domains, including academic difficulties, social problems, and psychiatric disorders. Therefore it is reasonable to ask, Why place so much emphasis on self-control problems? Some at-risk children are better at self-control than others, and at-risk children who have better self-control abilities are more likely to be at least average in their academic, social, and emotional functioning. Head Start children who perform better on self-control tasks are described by their preschool teachers as engaging in more on-task behavior (Blair & Peters, 2003) and go on to have higher math and literacy abilities when they get to kindergarten (Blair & Razza, 2007). A study of homeless 5- and 6-year-old children during the transition to school also showed that self-control was related to school readiness (Obradović, 2008). Among the homeless children, those who did better on self-control tasks were later rated by their teachers as having stronger academic abilities, higher peer competence, and fewer psychiatric symptoms. For at-risk children, self-control may be an important tool for success in overcoming adversity and getting on a positive developmental path.

Helping Children Develop Self-Control

Improving self-control in children at risk could be beneficial not only to their current functioning but also for the many long-term developmental outcomes associated with self-control. Numerous interventions focus on trying to address negative outcomes associated with self-control, such as antisocial behavior problems and academic difficulties, but it can be challenging to get children back on track once they have had these problems for a while. Early behavior problems and academic failures tend to have a snowballing effect, in which the child gets further and further off course in both socio-emotional and academic functioning. Focusing interventions on developing self-control in early childhood may help to prevent these later negative outcomes from developing in the first place (Diamond, Barnett, Thomas, & Munro, 2007). We know that learning experiences in early childhood help shape developing brain regions that are important for self-control. What if an intervention program could provide children with the specific types of experiences they need to train their brains to have better self-control? Recently, researchers have developed training programs to do just that, with a curriculum designed to target the brain regions underlying self-control. These programs are geared specifically to improving control of attention, cognition, and the ability to suppress impulses. Improvements in these aspects of self-control can improve academic functioning as well as give children strategies to cope with social and emotional situations.

One example of this type of program is the *Tools of the Mind* curriculum, a set of 40 activities to help children learn to resist impulses, ignore distractions, hold information in mind, and think flexibly (Diamond et al., 2007). These activities are designed to be incorporated into the daily routines of preschool and kindergarten classrooms, to provide children with strategies to

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Bilingual children do better than monolingual children on some attention control tasks.

Learn More

Tools of the Mind
Preschool program improves cognitive control
A. Diamond, W. S. Barnett, J. Thomas, & S. Munro 2007
Science, 318, 1387–1388

On-line supplemental materials: www.sciencemag.org/cgi/content/full/318/5855/1387/DC1

This is one example of a program to improve control of attention and cognition, designed to be incorporated into a preschool or kindergarten classroom on a daily basis. The supplemental materials provide information about the *Tools of the Mind* curriculum and evidence for the program's effectiveness. As detailed in the supplement, strategies used by this program to improve self-control include the following:

1. Provide concrete, external aids to remind children to stay "on task," such as a clean up song.
2. Have one child perform a task, such as counting, and a second child then check his partner's work. The goal is to promote turn taking and self-monitoring.
3. Encourage children to use "private speech," talking to themselves out loud to remind themselves of a sequence of directions that they are following. Speaking out loud also is intended to help children resist an impulse when rules change, such as first learning to clap when they are shown a picture of a square and then changing the rule and learning to stomp in response to a square.
4. Provide opportunities for dramatic play. Children plan out a play scenario in advance, through discussion or by drawing it, to give them practice developing planning skills. Role-playing also may help children learn impulse control, because they must remain in character and inhibit behaviors that would not fit their role in the game.

Attention Skills Training Program
www.teach-the-brain.org/learn/downloads/index.htm

This curriculum was developed by Rueda, Rothbart, et al. (2005) as a brief intervention to help preschool children improve control of attention. It is available to download for free at this Web site.

support and opportunities to practice control of attention and cognition. For example, children hold a drawing of an ear to remind them to listen; are taught to tell themselves out loud what they should do; and use drawings to plan out their dramatic play scenarios in advance, to practice planning and memory. Low-income, urban preschool children who received this *Tools of the Mind* curriculum all year did better on attention-control tasks administered at the end of the school year compared with peers who received a standard literacy curriculum. These tasks are known to involve the prefrontal cortex. The more complicated the task, the greater the advantage of the children who had received the *Tools of the Mind* curriculum (Diamond et al., 2007). What makes this finding particularly exciting is that this was not a case of "teaching to the test." Children were not trained at all on the specific tasks used as outcome measures, and they indeed had never seen these tasks before. The curriculum led to generalized improvements in control of attention and cognition, suggesting that for these at-risk children, the daily learning experiences effectively targeted brain regions, like the prefrontal cortex, which are involved in control.

Another attention-control curriculum, the *Attention Skills Training Program*, provides direct evidence that training can change brain activity patterns (Rueda, Rothbart, et al., 2005). This 5-day intensive training program was conducted with typically developing 4- and 6-year-old children. It included computer games designed to require attention control, such as moving a cat to a grassy area and avoiding the muddy ones, or clicking on sheep but not on wolves. Children performed better on attention-control tasks after receiving the training. Moreover, the pattern of event-related potentials (ERPs, which are a type of brain wave response) while completing the task was more mature in children who had received training. The ERPs of trained 4-year-olds resembled those of untrained 6-year-olds, and the ERPs of trained 6-year-olds resembled those of older children and adults (Rueda, Rothbart, et al., 2005). This study suggested that targeted attention skills training can teach the anterior cingulate and prefrontal cortex to function in a more mature, efficient way during attention-control tasks. Programs like *Tools of the Mind* and *Attention Skills Training* offer promising indications that a curriculum that targets specific brain regions involved in self-control can help children at risk to develop better self-control. More research is needed to document whether the self-control gains from these training programs are maintained over time and to determine whether the children's improved self-control leads to improvements in academic, social, and psychiatric functioning over the long term.

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